

200P

7

# VON KARMAN CENTER

S N A P - 8 D I V I S I O N

## BIBLIOGRAPHY ON LIQUID METALS TECHNOLOGY OF Hg, K, Na, AND NaK

A REPORT TO  
NATIONAL AERONAUTICS AND  
SPACE ADMINISTRATION

Report No. 2550/September 1963

COPY NO.

084

FACILITY FORM 802

N64-33194

(ACCESSION NUMBER)

471

(PAGES)

NACA CR 59028

(NASA CR OR TMX OR AD NUMBER)

(THRU)

(CODE)

(CATEGORY)

OTS PRICE

XEROX

MICROFILM

\$

\$

2.21 PS  
2.25 MF





---

BIBLIOGRAPHY ON LIQUID METALS TECHNOLOGY  
OF Hg, K, Na, AND NaK

a report to

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Contract No. NAS-5-417

Report No. 2550

September 1963

---

**AEROJET-GENERAL CORPORATION**  
A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY

OTS PRICE

XEROX

\$

2.71 FS

MICROFILM

\$

2.25 mf

BIBLIOGRAPHY ON LIQUID METALS TECHNOLOGY

OF Hg, K, Na, AND NaK

Report No. 2550

Prepared by:

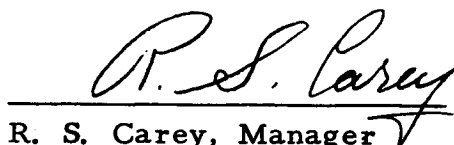
Dr. P. L. Studt  
I. M. Rehn  
J. T. Jouthas

Approved by:



G. W. Titus, Manager  
Metallurgy Department  
Aerojet-General Nucleonics

Approved by:



R. S. Carey, Manager  
Materials Department  
SNAP-8 Division  
Aerojet-General Corporation

SNAP-8 Division  
AEROJET-GENERAL CORPORATION  
Azusa, California





## FORWARD

This bibliography was compiled at the direction of R. S. Carey, Manager, and H. D. Derow, Assistant Manager, Materials Department, SNAP-8 Division, Aerojet-General Corporation.

The compilation was performed at Aerojet-General Nucleonics, San Ramon, California, and was organized under R. S. Carey and supervised by P. F. Young. The compilation was prepared by Dr. P. L. Studt, I. M. Rehn, and J. T. Jouthas assisted by F. H. Cassidy and M. F. Parkman.



## CONTENTS

### INTRODUCTION

### OUTLINE

- 1.000 CORROSION FUNDAMENTALS: SNAP-8  
MATERIALS
- 2.000 CONTAINMENT MATERIALS FOR LIQUID METAL SYSTEMS
- 3.000 LIQUID METALS
- 4.000 EFFECT OF DESIGN AND FABRICATION PARAMETERS ON  
CORROSION BY LIQUID METALS
- 5.000 EFFECT OF LOOP OPERATION ON PERFORMANCE
- 6.000 LOOP COMPONENTS
- 7.000 TECHNIQUES OF CORROSION TESTING
- 8.000 BIBLIOGRAPHIES - REPORTS OF PROCEEDINGS AND  
SYMPOSIUMS - GENERAL COMPENDIUMS OF LIQUID  
METALS TECHNOLOGY
- 9.000 INDEX



O U T L I N E



## INTRODUCTION

Many organizations have done, and are currently doing a great amount of liquid metal corrosion research. As a result of this research, numerous reports on the subject have been published with the support and under the cognizance of many agencies.

This information is essential to anyone conducting programs wherein liquid metals are used. Availability of the data ensures consideration of state-of-the-art developments in a field that is expanding at an increasingly rapid pace.

This bibliography, published under the auspices of the SNAP-8 Program, attempts to consolidate pertinent liquid metals corrosion information and will be of particular value to the several SNAP systems development programs.

Periodic supplements to this document will be issued to maintain currency. At the completion of the task, a final report will be issued that will include a complete review of all abstracted articles and a compilation of significant data.

This bibliography was compiled with respect to and in the order of the enclosed outline. These abstracts were taken from the following published works:

- 1) Nuclear Science Abstracts, (NSA), Vol. 5 (1951) through Vol. 17, No. 4 (1963)
- 2) Chemical Abstracts, (CA), Vol. 50 (1956) through Vol. 57, No. 4 (1963)
- 3) MSA Research Corporation, LM/Tab 1 (1956) through LM/Tab 21 (1963)
- 4) Scientific Technical Aerospace Reports, Vol. 1 (1961) through Vol. 1, 1963
- 5) International Atomic Energy Agency, Vol. 2, No. 11 May 1960 through Vol. 5, No. 5, March 1963.
- 6) ASTIA and NASA Documents
- 7) American Society for Metals Literature
- 8) Miscellaneous reports and literature.

The abstracts included herein were copies in their original context, and as a result the reader will find that the format changes with abstract source. To aid the reader, all titles are underlined. A few of the subjects listed in the outline have no cited references. A supplement is planned to fill in these omissions with both original and cross-index references.

To facilitate the use of this volume the NSA and CA are listed in numerical order in the index. Included is a list of abbreviations of the various corporate authors. The major contributing organizations have been indexed, but no attempt was made to index the foreign literature and journals.



1.000 CORROSION FUNDAMENTALS :

SNAP-8 MATERIALS

- 1.100 General Character of Liquid Metal Corrosion
  - 1.110 Types of Corrosion
  - 1.120 Solubility in Liquid Metals
  - 1.130 Structure of Liquids and Compound Formation
- 1.200 Mass Transfer and Kinetics of Corrosion
  - 1.210 Rate Controlling Steps
  - 1.220 Diffusion Controlled Effects
  - 1.230 Effect of Temperature Gradients
  - 1.240 Effects of Radiation
- 1.300 Dynamic Loop Corrosion
  - 1.310 Flow Rate and Erosion Effects.
  - 1.320 Deposition of Solutes
  - 1.330 Boiling and Vapor Phase Effects
  - 1.340 Condensation of Vapor
- 1.400 Selective Effects on Alloys Caused by Alloying Elements and System Impurities
  - 1.410 Accelerated Corrosion Due to Oxygen, Nitrogen, and Other Gases
  - 1.420 Accelerated Corrosion Due to Metallic Solutes
  - 1.430 Embrittlement of Containment Materials
- 1.500 Intergranular Attack and Embrittlement
  - 1.510 Basic Causes
  - 1.520 Metallurgical Conditions Contributing to Intergranular Attack
  - 1.530 Liquid Metal Properties Leading to Special Corrosion Problems
- 1.600 Techniques to Minimize Corrosion
  - 1.610 Metallurgy of Containment Materials
  - 1.620 Purification and Gettering of Liquid Metals
  - 1.630 Inhibitors
  - 1.640 Design Parameters

2.000 CONTAINMENT MATERIALS  
FOR LIQUID METAL SYSTEMS

- 2.100 Summary of Physical and Mechanical Properties of Loop Materials
  - 2.110 Ferritic and Martensitic Steels
  - 2.120 Austenitic Steels and High Temperature Alloys
  - 2.130 Nickel and Cobalt Base Alloys
  - 2.140 Refractory Metals
  - 2.150 Other Nonferrous Metals
  - 2.160 Nonmetallic Materials
- 2.200 Relative Corrosion Resistance of Containment Materials for Liquid Metal Service
  - 2.210 Mercury Service
    - 2.211 Pure Metals
    - 2.212 Ferritic and Martensitic Steels
    - 2.213 Austenitic Steels and High Temperature Alloys
    - 2.214 Nickel and Cobalt Base Alloys
    - 2.215 Refractory Metals
    - 2.216 Other Nonferrous Metals
    - 2.217 Nonmetallic Materials
  - 2.220 Potassium Service
    - 2.221 Pure Metals
    - 2.222 Ferritic and Martensitic Steels
    - 2.223 Austenitic Steels and High Temperature Alloys
    - 2.224 Nickel and Cobalt Base Alloys
    - 2.225 Refractory Metals
    - 2.226 Other Nonferrous Metals
    - 2.227 Nonmetallic Materials
  - 2.230 Sodium Service
    - 2.231 Pure Metals
    - 2.232 Ferritic and Martensitic Steels
    - 2.233 Austenitic Steels and High Temperature Alloys
    - 2.234 Nickel and Cobalt Base Alloys
    - 2.235 Refractory Metals
    - 2.236 Other Nonferrous Metals
    - 2.237 Nonmetallic Materials

- 2.240 NaK Service
  - 2.241 Pure Metals
  - 2.242 Ferritic and Martensitic Steels
  - 2.243 Austenitic Steels and High Temperature Alloys
  - 2.244 Nickel and Cobalt Base Alloys
  - 2.245 Refractory Metals
  - 2.246 Other Nonferrous Metals
  - 2.247 Nonmetallic Materials
- 2.300 Summary of Loop Corrosion Experience
  - 2.310 Mercury Loops
  - 2.320 Potassium Loops
  - 2.330 Sodium Loops
  - 2.340 NaK Loops
  - 2.350 Systems Involving Two or More Loops With Dissimilar Metals
- 2.400 Effect of Stress on Liquid Metal-Containment Interactions

### 3.000 LIQUID METALS

- 3.100 Selected Properties
  - 3.110 General Physical Properties
    - 3.111 Vapor Pressure of Liquid Metals
    - 3.112 Viscosity, Wetting, and Surface Tension
  - 3.120 Thermal Properties and Heat Transfer
  - 3.130 Nuclear Properties
  - 3.140 Chemical Properties
- 3.200 Purification of Liquid Metals
  - 3.210 Mercury (Hg)
    - 3.211 Impurities
    - 3.212 Method for Removal of Impurities
  - 3.220 Potassium (K)
    - 3.221 Impurities
    - 3.222 Method for Removal of Impurities
  - 3.230 Sodium (Na)
    - 3.231 Impurities
    - 3.232 Method for Removal of Impurities

- 3.240 Sodium-Potassium Alloys (NaK)
  - 3.241 Impurities
  - 3.242 Methods for Removal of Impurities
- 3.300 Chemical Analysis of Liquid Metals (techniques)
  - 3.310 Mercury (Hg)
  - 3.320 Potassium (K)
  - 3.330 Sodium (Na)
  - 3.340 Sodium-Potassium Alloys (NaK)
- 3.400 Solubility of Metals and Other Elements in Liquid Metals
  - 3.410 Mercury (Hg)
  - 3.420 Potassium (K)
  - 3.430 Sodium (Na)
  - 3.440 Sodium-Potassium Alloys (NaK)

4.000 EFFECT OF DESIGN PARAMETERS  
ON CORROSION BY LIQUID METALS

- 4.100 Mercury Loop and Design
  - 4.110 Corrosion Dependence on System Configuration
    - 4.111 Solution of Loop Containment Materials and Precipitation of Same
    - 4.112 Crevice Corrosion
    - 4.113 Stress Rupture
    - 4.114 Erosion
  - 4.120 Weld Structure, Brazements, and Connections
    - 4.121 Joints and Seals
    - 4.122 Chemical Compatibility
  - 4.130 Fatigue of Expansion/Contraction Components
  - 4.140 Bearings and Bearing Surfaces
- 4.200 Potassium Loop Design
  - 4.210 Corrosion Dependence on System Configuration
    - 4.211 Solution of Loop Containment Materials and Precipitation of Same
    - 4.212 Crevice
    - 4.213 Stress Rupture
    - 4.214 Erosion

- 4.220 Weld Structure, Brazements, and Connections
  - 4.221 Joints and Seals
  - 4.222 Chemical Compatibility
- 4.230 Fatigue of Expansion/Contraction Components
- 4.240 Bearings and Bearing Surfaces
- 4.300 Sodium Loop Design
  - 4.310 Corrosion Dependence on System Configuration
    - 4.311 Solution of Loop Containment Materials and Precipitation of Same
    - 4.312 Crevice Corrosion
    - 4.313 Stress Rupture
    - 4.314 Erosion
  - 4.320 Weld Structure, Brazements, and Connections
    - 4.321 Joints and Seals
    - 4.322 Chemical Compatibility
  - 4.330 Fatigue of Expansion/Contraction Components
  - 4.340 Bearings and Bearing Surfaces
- 4.400 Sodium-Potassium Alloys (NaK) Loop Design
  - 4.410 Corrosion Dependence on Systems Configuration
    - 4.411 Solution of Loop Containment Materials and Precipitation of Same
    - 4.412 Crevice Corrosion
    - 4.413 Stress Rupture
    - 4.414 Erosion
  - 4.420 Weld Structure, Brazements, and Connections
    - 4.421 Joints and Seals
    - 4.422 Chemical Compatibility
  - 4.430 Fatigue of Expansion/Contraction of Components
  - 4.440 Bearings and Bearing Surfaces

5.000 EFFECT OF LOOP OPERATION  
ON PERFORMANCE

- 5.100 Surface Preparation of Containment Material
  - 5.110 Clean-up and Preparation Requirements for Mercury Systems
  - 5.120 Clean-up and Preparation Requirements for Potassium, Sodium, and NaK Systems

- 5.200 Purification, Gettering, and Filtering of Liquid Metals
  - 5.210 Mercury (Hg)
  - 5.220 Potassium (K)
  - 5.230 Sodium (Na)
  - 5.240 Sodium-Potassium Alloys (NaK)
- 5.300 Reaction of Contaminants in Liquid Metal
- 5.400 Fluid Flow and Heat Transfer Parameters
- 5.500 Handling Procedures for Safety and Purity Requirements
- 5.600 Cover Gas Effects

#### 6.000 LOOP COMPONENTS

- 6.100 Measurement Devices
  - 6.110 Flow Meters
  - 6.120 Liquid Level Measurement Devices
  - 6.130 Temperature Measurement Devices
  - 6.140 Pressure Measurement Devices
  - 6.150 Corrosion-Erosion Measurement Devices
  - 6.160 Liquid Impurity Content Measurement Devices
  - 6.170 Loop Plugging Indicators
- 6.200 Pumps
  - 6.210 Electromagnetic
  - 6.220 Mechanical
- 6.300 Valves
- 6.400 Heat Transfer Components
- 6.500 Other Components (Sampling devices, insulation, crud separators.)

#### 7.000 TECHNIQUES OF CORROSION TESTING

- 7.100 Static Corrosion Measurements
  - 7.110 Early Capsule Tests
  - 7.120 Testing of Several Materials in One Liquid Metal Capsule
  - 7.130 Single Material Capsule Tests
- 7.200 Dynamic Capsule Techniques
  - 7.210 Seesaw or Agitated Capsules
  - 7.220 Thermal Convection Techniques
  - 7.230 Boiling and Condensing Tests

- 7.300 Loop Corrosion Tests
  - 7.310 Thermal Convection Loops
  - 7.320 Electromagnetic Pumped Loops
  - 7.330 Centrifugal and Other Mechanical Pump Systems for High Flow Rate Loops and Systems
  - 7.340 Boiling and Condensing Loop Systems
- 7.400 Techniques for Evaluating Corrosion Effects
  - 7.410 Dimensional and Mass Transfer Measurements
  - 7.420 Analysis of Liquid and Precipitated Phases
  - 7.430 Methods for Evaluating Corrosion Nondestructively
  - 7.440 Chemical Evaluation of Containment Materials
  - 7.450 Metallographic and Advanced Metallurgical Techniques for Evaluating Corrosion and Associated Material Changes
  - 7.460 Changes in Mechanical and Physical Properties

8.000 BIBLIOGRAPHIES - REPORTS OF  
PROCEEDINGS AND SYMPOSIUMS -  
GENERAL COMPENDIUMS OF LIQUID  
METALS TECHNOLOGY

9.000 INDEXES

- 9.100 Numerical Index for Nuclear Science Abstracts (NSA)
- 9.200 Numerical Index for Chemical Abstracts (CA)
- 9.300 List of Abbreviations
- 9.400 Major Contributing Organizations (Corporate Authors)
- 9.500 Index of SNAP-8 Topics





1.000

CORROSION FUNDAMENTALS:

SNAP-8 MATERIALS



- 1.100 FACTORS INFLUENCING THE SOLUBILITY OF SOLID METALS IN LIQUID METALS. J. R. Weeks, BNL. Presented at the 12<sup>th</sup> Annual AEC Corrosion Symposium, May 20-22, 1963, Castlewood, Pleasanton, California

Knowledge of the solubility of a solid metal in a liquid metal, and of its temperature dependence, is essential to application of any theory of liquid metal corrosion.

At equilibrium, one can derive

$$\Delta H = T \left[ \Delta_{\text{fusion}} + \Delta S_{\text{excess}} - R \log (n) \right]$$

where  $\Delta H$  is the partial molal heat of solution of the solute atom and  $n$  is the mol fraction of solute in the saturate liquid. Thus a plot of  $\log (n)$  as a function of  $1/T$  is expected to yield a straight line, the slope and intercept of which yield respectively  $\Delta H$  and the excess entropy of solution.  $\Delta H$  represents the force of attraction between the solute and solvent metals.  $\Delta S_{\text{excess}}$  gives an indication of the association or order between solute and solvent atoms in the liquid solution. The relative values of  $\Delta S_{\text{excess}}$  for slightly-soluble solutes may be related to the relative vapor pressures of the solid metals. The presence in the liquid metal of trace impurities may override the basic solubility relationship in the clean system.

Data will be presented that lend support to each of the above conclusions.

- 1.100 The Liquid Metal Corrosion Problems  
Dvorak, Alois (Akimov State Univ., Prague)  
Jaderna energie 6, 1555-62 (1960) In Czech.  
NSA 14:16968

Recent research on the specific character of corrosion of construction materials by liquid metals as well as factors influencing the development of these corrosion processes are reported. The characteristic effects of corrosion by liquid metals, the principles of corrosion test methods, and the main methods of increasing the corrosion resistance of construction materials are given.

- 1.100 Static and Dynamic Corrosion and Mass Transfer in Liquid Metal Systems  
Epstein, Leo F. (Knolls Atomic Power Lab., Schenectady, N. Y.)  
Chem. Eng. Progr. Symposium Ser. 53, No. 20, 67-81 (1957).

In many systems involving liquid metals, corrosion of a solid exposed to the fluid is by simple solution. In a static isothermal assembly the rate of corrosive attack is determined by the solution rate. The value of this parameter depends on whether the rate-determining step is (1) the diffusion of the solute through the liquid or (2) transfer of the solute through a solid film or some product of chemical reaction at the solid-liquid interface. In dynamic corrosion, such as is encountered in heat-transfer loops, where parts of the system are at different temperatures and the fluid flows continually from the hot to the cold zone, different expressions are obtained for the corrosion rate, depending on whether mechanism 1 or 2 is more important. These results are examined for a few solid-liquid metal systems, and quantitative relations capable of yielding order-of-magnitude agreement with expt. are obtained. The material dissolved in the hot zone of a heat-transfer loop tends to deposit out of solution in the cold zone, resulting in an overall transport of material. Factors influencing this mass transfer rate are examined. The effects of minor impurities in the solvent in accelerating and inhibiting corrosion are discussed.

CA 51:16260

- 1.100 Fundamentals of Liquid Metals Corrosion  
W. D. Manley, Corrosion Vol 12, pp 336t-342t (1956)

Six fundamental processes of liquid metal corrosion are indicated and discussed, including

- 1) Simple solution
- 2) Alloying between liquid and solid metal
- 3) Intergranular penetration
- 4) Impurity reactions
- 5) Temperature-gradient mass transfer
- 6) Concentration gradient (or dissimilar-metal) mass transfer

Nine variables affect these processes:

- 1) Temperature
- 2) Temperature gradient
- 3) Cyclic temperature fluctuation
- 4) Surface-area to volume ratio
- 5) Purity of liquid metal
- 6) Flow velocity (Reynold's number)
- 7) Surface condition of container material
- 8) Number of materials in contact with the same liquid metal
- 9) Condition of the container material (grain-boundary precipitate, state of stress, grain size)

- 1.100 SOLID METAL-LIQUID METAL REACTIONS IN BISMUTH AND SODIUM.  
John R. Weeks and David H. Gurinsky (Brookhaven National Lab., Upton, N. Y.). Liquid Metals and Solidification, Seminar 39th Natl. Metal Congr., Chicago 1957, 190-63 (Pub. 1958).

A 44 reference review of the current status of the theory of solid-liquid metal interactions (or corrosion) and its possible applications to the construction of a liquid U-Bi fueled nuclear reactor is given.

CA53-2991f

- 1.100 Compatibility Between Solid and Liquid Metals. "Australian Atomic Energy Symposium, 1958"

Compatibility between solid and liquid metals is defined. Several mechanisms are described by which compatibility may be reduced. The types of tests which are used to assess compatibility are also described. A description is given of investigations into the compatibility of niobium with liquid sodium.

NSA 14:1210

- 1.100 TID 3544  
Symposium on Corrosion Fundamentals. A series of lectures presented at the University of Tennessee Corrosion Conference at Knoxville on March 1, 2, 3, 1955. Anton de S. Brasunas and E. E. Stansburg, eds. Knoxville, University of Tennessee Press, 1956. 260p. NSA 12:2908

- 1.100 AD-259-250 Problems of Corroding Structural Materials by Liquid Metals, Dvoralc, A. (translation from Russian)

Data are presented on the specific nature of destruction of structural material by liquid (hot) metals and the actual influences of these corrosive actions. Characteristic investigations of corrosion caused by hot metals, principles of corrosion testing and measures leading to increasing the corrosion resistance of structural materials are discussed.

- 1.100 Cambridge Univ. (England) INTERACTIONS BETWEEN SOLID AND LIQUID METALS AND ALLOYS; SECOND ANNUAL TECHNICAL REPORT, by V. W. Eldred. Sept. 1951. 72p (AERE-X/M-85)

A method has been developed for bringing clean surfaces of fully annealed metals in contact with filtered and degassed liquid metals and keeping them in contact for long periods, without oxide contamination, so that the rate and nature of the attack by the molten metal may be investigated. The method can be used with many of the lower melting point metals at temperatures below 500°C and may be extended to higher temperatures. Tests have been carried out at temperatures up to 400°C on pure metal systems in which little attack was anticipated. A few tests have also been included on systems in which severe attack was expected. The interpretation and practical application of the results are discussed. (auth)

NASA Vol. 6 - 6603

---

## 1.110 TYPES OF CORROSION

- 1.110 Liquid Metal Corrosion Mechanisms  
J. R. Weeks, C. J. Klamut and D. H. Gurinsky  
U.S. Atomic Energy Commission, Washington, D.C., USA  
Conference on Corrosion of Reactor Materials, Salzburg, June 1962,  
International Atomic Energy Agency

The corrosion of solid metals by these coolants and fuels is a complex process. Kinetics of dissolution and precipitation of solid metals in liquid metals, and complex multi-component solubilities and their temperature coefficients are both part of the corrosion mechanism. In addition, non-metallic impurities (O, N, C) affect both the kinetics and the solubilities.

An atom of a solid metal dissolves in a liquid metal by breaking its bonds with its neighbor like-atoms and forming new ones with liquid atoms. This process is dependent on the structure at the solid-liquid interface. The dissolved atom then migrates, perhaps with its "solvation sheath," through the relatively quiet liquid adjacent to the solid metal into the main body of coolant. This migration is a function of the liquid flow. The exchange of electrons that occurs during dissolution of the solid metal is not well understood; it is likely to influence both the dissolution and diffusion processes, as indicated by electro-diffusion experiments.

The magnitude and temperature coefficients of the solubilities of solid metals in liquid metals cannot be predicted by the present theories of liquid alloys. They appear to depend upon the band structure of the liquid alloy, and upon the relative atomic diameters of the solute and solvent atoms in the liquid alloy. Magnetic susceptibility, electrical resistivity, and alloy density measurements are useful guides in advancing the theory. Precise experimental liquidus measurements of very dilute alloy systems are at present the most reliable means of interpreting the corrosion mechanisms in a given system.

O, N, and C in many cases catalyze corrosion by liquid metals. They both accelerate the dissolution rate and increase the solubility of many solid metals in alkali liquid metals, presumably by forming soluble complexes. Zr and Ti additions to the liquid metals inhibit corrosion of steels by Pb, Bi, and Hg by reacting with C and/or N in the steel to form surface deposits of carbides and/or nitrides which are a barrier to dissolution.

Examples will be cited from the literature and from the authors' own work that illustrate the kinetic and thermodynamic processes occurring during liquid metal corrosion.

1.110 THE EFFECT OF MOLTEN ALKALI METALS ON CONTAINMENT METALS AND ALLOYS AT HIGH TEMPERATURES

Amateau, M. F.

Defense Metals Information Center, Battelle Memorial Institute  
DMIC Report 169, May 28, 1962, 54p.

Extensive review of literature on the effects of Na and NaK alloys, liquid Li and liquid and gaseous K, Rb, and Cs on the corrosion and sliding and bearing properties of pure metals and alloys including stainless steel, superalloys and refractory metals. Topics include types of liquid-metal corrosion, factors affecting liquid-metal corrosion and techniques for investigating such. 71 ref. (R6m, 2-62; SGA-h, SS, EG-337)

1.110 AD259-250, 11 July 1961. Problems of Corroding Structural Materials by Liquid Metals (Translation)

Data are presented on the specific nature of destruction of structural materials by L. M. (hot) and the influence of these corrosive actions. Characteristic investigations of corr. caused by hot metals, principles of corr. testing & measures leading to increasing corr. resist. of S. materials are described.

1.110 Corrosion of Iron and Steels in Liquid Metals.

I. Static Corrosion Test

Imai, Y. and Ishizaki, T.

Tohoku Univ., Sendai

J. Atomic Energy Soc., Japan 2, 96-101 (1960), Feb.

The modes of attack by liquid metal are direct alloying, dis-solution, intergranular penetration, corrosion by contaminants, and others. Microscopic examination of metallographically polished surface was adopted to investigate the attack of liquid metals on iron and steels. The reliability of the experimental method, the effect of oxygen and the effect of stabilizer of oxygen were examined.

NSA 14:12859

1.110 Liquid Metal Corrosion

E. E. Hoffman

Corrosion Fundamentals

University of Tennessee Press (1956)

Ni was observed to migrate through Na at 1000°C to form a reaction layer on a Mo surface.

1.110 AERE-X/R-1806

Interactions Between Solid and Liquid Metals and Alloys

Eldred, V. W.

Cambridge (Univ.), England (1953).

This report was written in the early part of 1953 and was based on work carried out at Cambridge in the preceding three years.

A technique for carrying out long-term corrosion tests is described. It has been applied to the investigation of over forty systems involving pure metals in contact with liquid Bi, Cd, Pb, Hg, K, Na, Sn and Zn at temperatures up to 550°C for periods of contact up to 300 hr. A series of ferrous and non-ferrous alloys has also been investigated under similar conditions in contact with the same liquid metals. The types of attack observed are described and discussed. Criteria for the classification of combinations of solid and liquid metals and alloys according to their corrosive behavior are put forward and applied to the systems investigated. The factors controlling the rate of solution of a solid metal in a liquid metal under various conditions are discussed theoretically in the light of the experimental results. The knowledge at present available with regard to metals and alloys manifesting a high corrosion resistance to liquid metals is considered and the characteristics of such systems are discussed. A method of predicting further systems of a similar character is suggested.

1.110 FUNDAMENTALS OF LIQUID-METAL CORROSION

Manly, W. D.

U. S. Atomic Energy Commission ORNL-2055, 10 pp. (1956).

The corrosion of structural metals by liquid metal proceeds by (1) simple solution, (2) alloying between liquid metal and solid metal, (3) intergranular penetration, (4) impurity reaction, (5) temperature gradient mass transfer, or (6) concentration gradient mass transfer. Examples are given and factors governing the occurrence of these phenomena are outlined.

CA 50:15401

1.110 Fundamentals of Liquid Metal Corrosion

Manly, W. D.

Corrosion 12, No. 7, 46-52(1956).

The corrosion of structural metals in liquid metal is for the most part a result of solubility of the various constituents of the metal alloy in the liquid metal. The manner in which this solution manifests itself gives rise to many types of attack, ranging from a simple solution type attack to a deep intergranular attack with the preferential leeching of one constituent of an alloy. Examples of the many types of corrosion experienced with solid metal-liquid metal systems are illustrated. The role of impurities on the corrosion is discussed.

In addition to the solution stage, which would soon disappear in a static one metal system on reaching a solubility limit, the corrosion of metals can be continued through the removal of materials from solution in the liquid metal with a temperature gradient or by dissimilar metal transfer. The transfer of metal in a plumbing system by the mechanism of mass transfer-temperature gradient and dissimilar metal transfer will greatly increase the amount of corrosion as compared to the results obtained at static systems. Examples of temperature gradient mass transfer and dissimilar metal transfer are reviewed, and factors governing the occurrence of these phenomenon are outlined.

1.110 Liquid Metal Corrosion Mechanisms

J. R. Weeks and C. J. Klamut

BNL-6102

Dissimilar metal effects have been observed in several liquid metal systems, including Na, Bi, and Hg. The mechanism involving a solubility product of two metallic solutes at low concentration was considered. The effect of nonmetallic solutes is generally more decisive on corrosion rates.

1.120 SOLUBILITY IN LIQUID METALS

1.120 HEAT TRANSFER THROUGH MOLTEN MATERIALS

Inco Corrosion Reporter, v. 9, no. 2, Oct 1962, 13p.

Mechanism of liquid metal corrosion at high temperatures and under pressure in nuclear reactors as a function of solution rate and solubility limit of the solid metal in the liquid. Advantages and limitations of liquid metals as heat transfer media and use of 18-8 stainless steel with Na and NaK and Ni alloy Inor 8 with fluoride salt mixtures. 5 refs.

1.120 POSSIBLE CORRELATIONS BETWEEN THERMOELECTRIC POTENTIALS AND LIQUID METAL CORROSION

J. R. Weeks (1960) 6 p. (BNL-5574)

A possible explanation for the following liquid metal corrosion phenomena: selective attack, and solution rate... it is assumed that the thermoelectric potentials between the corroding surface and the liquid metal influence the dissolution rate.

NSA 17:3421

- 1.120 FACTORS INFLUENCING THE SOLUBILITY OF SOLID METALS IN LIQUID METALS. J. R. Weeks, BNL. Presented at the 12<sup>th</sup> Annual AEC Corrosion Symposium, May 20-22, 1963, Castlewood, Pleasanton, California

Knowledge of the solubility of a solid metal in a liquid metal, and of its temperature dependence, is essential to application of any theory of liquid metal corrosion.

At equilibrium, one can derive

$$\Delta H = T \left[ \Delta_{\text{fusion}} + \Delta S_{\text{excess}} - R \log (n) \right]$$

where  $\Delta H$  is the partial molal heat of solution of the solute atom and  $n$  is the mol fraction of solute in the saturate liquid. Thus a plot of  $\log (n)$  as a function of  $1/T$  is expected to yield a straight line, the slope and intercept of which yield respectively  $\Delta H$  and the excess entropy of solution.  $\Delta H$  represents the force of attraction between the solute and solvent metals.  $\Delta S_{\text{excess}}$  gives an indication of the association or order between solute and solvent atoms in the liquid solution. The relative values of  $\Delta S_{\text{excess}}$  for slightly-soluble solutes may be related to the relative vapor pressures of the solid metals. The presence in the liquid metal of trace impurities may override the basic solubility relationship in the clean system.

Data will be presented that lend support to each of the above conclusions.

- 1.120 Diffusion and Chemical Control in the Dissolution of Metals in Mercury. Bennet, J. A. R., and J. B. Lewis  
J. Chim. Phys., 55:83-89; discussion 89-90 (1958)

The const. of dissolution of Pb, Sn, and Zn in Hg were compared with those of the dissolution of benzoic acid in water since the latter is known to be a process of controlled diffusion. The correlation between the data from the systems Sn-Hg, Pb-Hg, and benzoic acid-water, was sufficient to establish that the rates of dissolution of Sn and Pb in Hg represent a controlled-diffusion process. With Zn-Hg, dissolution is partly a chem. process and it was shown that, with single, cylindrical Zn crystals, the rate of dissolution was different for the different crystallographic faces. The same phenomenon was qual. observed with Bi and Cd. --J.S.C.

MA 26:663

- 1.120 AERE-CE/R-1998  
Transport and Chemical Control in the Dissolution of Metals In Mercury. J. A. R. Bennett and J. B. Lewis. June 1957. 48p.  
United Kingdom Atomic Energy Authority. Research Group.  
Atomic Energy Research Establishment, Harwell, Berks, England

The dissolution rates of tin, lead, and zinc in mercury and of benzoic acid in water and aqueous sucrose were investigated under conditions which solid cylindrical specimens are held stationary and concentric cells containing the solvent are rotated about them at predetermined speeds. The results indicate that the dissolution of tin and lead in mercury is transport controlled. The mass transfer coefficient data for these and the benzoic acid systems were correlated by the expression

$$\frac{KL}{v} = 0.018 \frac{Lu}{v}^{0.6} \frac{v}{n}^{-0.5}$$

The zinc data do not fit correlation due to the influence of the mean chemical rate with an activation energy of the order of 10 kcal/mole. Qualitative results obtained with single and multi-crystalline specimens of zinc indicate that different crystal planes of the zinc lattice dissolve at different rates. Data were also obtained for the dissolution of benzoic acid in water and aqueous sucrose by use of the expression

$$\frac{KL}{v} = 0.135 \frac{Lu}{v}^{0.6} \frac{v}{D}^{-0.6}$$

NSA 14:5064



Fundamental Research and Development in Metallurgy.

Anon.

Annual Report to the Research Division for the Period July 1957 to June 1958. Sept. 1, 1959. 27p. Contract AT(30-1)-1565. \$0.75(OTS). Nuclear Metals, Inc., Concord, Mass.

In earlier work it was found that solubilities of other metals in Hg, Ti, Pb, and Bi are related to the locations of the solutes in the periodic table. The survey was extended to include Cd, In, Sn, and Sb. Data on these solubilities are presented along with similar data for Al, Zn, and Ga. Research in deformation modes of Zr is reported. A summary of crystal growing techniques, reformation on twin elements are summarized in included abstracts and tables. Studies of Cu-Fe precipitation hardening alloys under neutron irradiation were completed. Abstracts of topical reports describing this work are also included. (J.R.D.).

NSA 13:22408

Liquid Metal Corrosion

E. E. Hoffman

Corrosion Fundamentals

University of Tennessee Press (1956)

Ni was observed to migrate through Na at 1000°C to form a reaction layer on a Mo surface.

Attack of Unstressed Metals by Liquid Mercury

J. F. Strachan and N. L. Harris. J. Inst. Metals 85, 17-24 (1956) (Paper No. 1715)

The solubilities and wt. losses in the absence of air at room temperature of most of the metallic elements in static liquid Hg were detd., usually to 0.001%, by chem. analysis of the solns. and by weighing the specimens. The solubilities show a periodic relationship with the at. no., and there are indications that this can be related to the inner electronic shell structure. In general, the solubilities of the B sub-group elements exceed those of the true metals, while of this latter group the transition metals show the lowest values. When attack occurs, it involves wetting, surface amalgamation, soln, and occasionally combination and intergranular penetration. Oxidation brought some metals out of soln. in Hg and led to ambiguities. Exposure to air can result in a form of mass transfer. No significant changes occurred in the mechanical properties of Fe, Mo, some steels, and Ni alloys after 2000 hrs in Hg at 500°. Ni suffered a decrease in maximum stress, yield stress, and elongation of about 50%. Severe cavitation erosion of metals and alloys, normally resistant to Hg, occurred at room temperature on the application of 30 kc./sec. ultrasonic vibrations.

CA51-981h

STRUCTURE OF LIQUIDS AND COMPOUND FORMATIONSolubility of Metals In Mercury, V. P. Gladyshev

(Fixika Metallov i Metallovedenie, 1960, 9, (6), 852-860)

(In Russian)

Theoretical. In a general discussion of the solubility, S, of various metals in Hg, it is shown that in the case of simple, binary amalgams contg. only one metal in soln., there is a definite relationship between S and the structure of the inner electron shells, energy of the at. bond in crystal-lattice magnitude of the first ionization potential and of the generalized moment of metal ions, and structure of liquid metals. The causes of the anomalous behaviour of certain metals (Na, Ba) and the relationship between increased S of metals in the Al-Sub-Group and their at. structure are also discussed. MHS

MA 28:868-26

- 1.130 THE MACROMOLECULAR STRUCTURE OF LIQUID METALS AND THE INTERACTION OF THE MACROMOLECULES  
Yu. A. Klyachko. Izvest. Akad. Nauk S.S.S.R. Otdel Tekh. Nauk, Met. i Toplivo, No. 6, 85-7 (Nov-Dec 1960)(In Russian)

The theory of the macromolecular and micelle type structures of liquid and solid metals is discussed.

NSA 15:11639

- 1.130 The Structural Model of Monatomic Liquids Including Metallic Liquids Near the Melting Points. Kazuo Furukawa. Tohoku University, Science Reports of the Research Institutes, Series A, v. 12, Aug. 1960, p. 368-383.

Data of atomic radial distribution curves for monatomic liquid near their melting points given for He, Ar, Xe, Li, Na, K, Au, Zn, Cd, Hg, Al, Ga, In, Tl, Ge, Sn, Pb, Sb and Bi. A simple structural model having only one parameter is proposed. Also data for molar volumes, self-diffusion coefficients, entropies and viscosity coefficients.  
(M25, P-general; 14-60) NSA 14:3499

- 1.130 LIQUID METALS AND SOLIDIFICATION

Sponsored by the ASM

A seminar on Liquid Metals and Solidification Held During the 39th National Metal Congress and Exposition, Chicago, Nov. 2 to 8, 1957.

The papers presented at this seminar include: The Theory and Structure of Liquids; Transport Properties in Pure Liquid Metals; Thermodynamics and Properties of Liquid Solutions; Nucleation in the Solidification of Metals; Solid Metal - Liquid Metal Reactions in Bi and Na; Discussion of Weeks and Gurinsky paper on Solid Metal - Liquid Metal Reactions in Bi and Na; Some Aspects of the Mechanism of Metal Deposition and Dissolution; Mechanism of Growth; Thermal Considerations of Freezing; Redistribution of Solute During Freezing; Imperfections Resulting from Solidification; Poly-phase Solidification; and Structure of Ingots and Castings.

NSA 13:9065

- 1.130 Structure of Liquid Metals by Radchenko, I. V.  
Uspekhi Fiz. Nauk 61, 249-76 (1957). Feb. (In Russian)

Roentgenographic and neutronographic investigations showed that the atomic packing in liquid metals is related to the atomic packing in the solid state, however, the character of such bond depends on the type of the metal. The coordination number of all metals either increases or changes. The indication of reduced coordination numbers for Pb, Tl, and In was not sufficiently substantiated due to the side maximum appearing on the atomic distribution curve. This could be an error incurred in developing the intensity distribution curves. The temperature relations of the intensity curves of K, Tl, Sn and other metals show that liquid metals retain their type of packing at considerably higher temperatures than the melting point.

NSA 11:7208

- 1.130 Interatomic Potential Functions of Sodium and Potassium  
Ling, Rufus C.  
J. Chem. Phys. 25, No. 4, 609-13 (1956).

The liquid structure theory of Born and Green is used to interpret X-ray diffraction measurements on liquid sodium and potassium to find an effective interatomic potential function for pairs of sodium and pairs of potassium atoms. This potential function predicts approximately the correct binding energy for solid sodium and potassium, and when reinserted in the X-ray formulas predict scattering curves at higher temperatures which are in good agreement with experiments.

- 1.130     SIGNIFICANT STRUCTURES IN THE LIQUID STATE. PARTS 1 to V, and THERMODYNAMIC AND TRANSPORT PROPERTIES OF MOLTEN METAL  
C. M. Carlson, H. Eyring, and T. Ree, National Academy of Sciences, Proceedings. Vol 44, 1958, p. 683-688, Part I  
Vol 45, 1959, p. 1594-1599, Part II  
Vol 46, 1960, p. 333-336, Part III  
Vol 46, 1960, p. 336-343, Part IV  
Vol 46, 1960, p. 649-569, Part V

Experiments carried out using the method of significant structures to calculate the thermodynamic and to predict the viscosities and self-diffusion coefficients of molten Na, Hg, Cu, and Pb. (AGN Lib. C-1 3-463)  
NSA 14:15083

- 1.130     X-Ray Scattering by Liquid Metal Alloys (A Kinetic Approach)  
Ling, R. C.  
J. Chem. Phys. 25, No. 4, 614-616 (1956)

The Born-Green theory of liquids is extended to the case of liquid mixtures and a formula for the X-ray scattering by such liquids is developed. The formula is used to calculate the X-ray scattering by a liquid sodium-potassium alloy, and fair agreement with the experimental scattering is found.

- 1.130     Viscosity and Molecular Structure of Liquid Metals  
Golik, A. Z.  
Stroenie i Fiz. Sviostava Veshchestva v Zhidkom Sastoyanii (kiev: Izdatel. Univ.) Shornik 1954, 83-5; Referat. Zhur., Khim. 1956. Abstr. No. 25031

Hg, Cd, and Zn, similar in their structure when liquid, were chosen to investigate the relation between the viscosity  $\eta$  and structure. The crit. temps. of Cd and Zn, 2529° and 2910°, resp., are detd. by the known relation of the crit. and boiling temps. of Hg. The curves  $\eta = f(t)$  for these metals appear higher when the crit. temp. of the substance is higher; similar phenomena are observed with liquid Li, Na, K, Pb, and Cs. The viscosity of the liquid alloys Cd in Hg and Zn in Hg was investigated. The curves  $\eta = f(t)$  lie between the curves of the components and are higher when the b.p. and, consequently, the crit. temps. are higher. The curves  $\eta = f(t)$  are identical for the following solns.: 20% Cd in Hg, and 8% Zn in Hg; 11% Cd in Hg, and 4.3% Zn in Hg; 8.3% in Cd in Hg and 3% Zn in Hg. The temp. effect on  $\eta$  is exponential. The facts cited show the relation between the viscosity and mol. structure in the liquid state, also the expediency of investigating groups of liquids of similar mol. packing and similar types of intermol bond. CA 52:3444a

- 1.130     Intermetallic Forces in Liquid Alloys  
Frost, B. R. T.  
Gt. Brit. Atomic Energy Research Establishment  
Harwell, Berks, England  
AERE-M/TN-21 July 1953 15 p.

The problem of the changes in structure and physical properties which occur when alloys melt is discussed. From a review of published data on this subject, it is concluded that the interatomic force which give rise to compound formation in the solid state are also satisfied in the disordered liquid structure. Suggestions are made for the systematic examination of a series of magnesium alloys to determine the effect of the electrochemical factor on the physical properties of liquid alloys.

NSA 13:10006

- 1.200 ER-5302  
SUNFLOWER SOLAR RANKINE SYSTEM MERCURY CORROSION AND CORROSION  
PRODUCT SEPARATOR STATUS SUMMARY. (TAPCO) April 16, 1963  
Presented at NASA, Lewis Research Center on the general topic  
of Mercury Corrosion and Corrosion Product Trapping Experience  
at TAPCO.

The report has been centered primarily around the effects and  
test results which have been noted to date on the mercury Rankine cycle  
systems. Corrosion product separators are discussed and their results  
analyzed.

- 1.200 MASS TRANSFER INVESTIGATION IN LIQUID METAL SYSTEMS  
Progress Letter No. 38, August 1, 1962 - August 31, 1962  
R. W. Lockhart (GEAP) Sept. 4, 1962. Contract AT(04-3)-189.  
13 p. (TID-17384).

Stainless steel and Na samples were analyzed after loop testing to  
determine the composition change of a stainless steel surface exposed to  
liquid Na. The composition gradient was found to be steep near the surface,  
whereas the surface Cr and Ni contents were very low.

NSA 17:6575

- 1.200 MASS TRANSFER INVESTIGATION IN LIQUID METAL SYSTEMS  
Progress Letter No. 39, September 1, 1962 - September 30, 1962  
R. W. Lockhart (GEAP) Oct. 5, 1962. Contract AT(04-3)-189.  
13 p. (TID-17386).

Stainless steel and Na samples were analyzed after loop testing to  
determine mass transfer behavior.

NSA 17:6576

- 1.200 CORROSION AND MASS TRANSFER IN ALKALI LIQUID METAL SYSTEMS  
(BNL-5771)  
J. R. Weeks. (BNL). p. 709-27 of "Materials Science and Technology  
for Advanced Applications", Englewood Cliffs, N. J., Prentice-Hall,  
Inc., 1962.

Liquid alkali metals offer attractive properties as coolants for  
space-vehicle power sources. They are usually contained in the high-melting  
body-centered cubic transition metals and their alloys. Steels at temperatures  
below 550 °C and refractory metals at higher temperatures. Corrosion can occur  
by two mechanisms: dissolution of the solid metal into the liquid alkali metal,  
and a chemical -- as opposed to intermetallic -- reaction resulting from the  
presence of nonmetallic impurities in either the liquid or solid metals.  
Dissolution -- corrosion is a function of solubility and hydrodynamic factors.  
It is rare in practical alkali metal systems except where high-Ni container  
alloys are used. "Chemical" corrosion is a function of the C, O, and N  
activity in both the liquid and solid metals; it is minimized by "gettering"  
both the solid alloy and the liquid metal for these impurities, and/or by cold-  
trapping the coolant to reduce the concentration of soluble oxides. Design of  
liquid-vapor systems requires knowledge of the relative aggressiveness of the  
bulk liquid and the fresh condensate.

NSA 17:6557

- 1.200 STATUS OF FAST OXIDE REACTOR AND SODIUM MASS TRANSFER PROJECTS  
R. W. Lockhart (GE) (TID-7623, p. 135-48)

Results of the investigation of mass transfer and corrosion of three  
types of steel loops containing Na at elevated temperatures.

NSA 15:28558

- 1.200 MASS-TRANSPORT AND CORROSION OF IRON-BASED ALLOYS IN LIQUID METALS  
G. W. Horsley (Atomic Energy Research Establishment, Harwell, Berks,  
Eng.). J. Nucl Energy Part B. Reactor Technol. 1. 84-91 (1959) Aug.

The application of mass-transport equations to the corrosion of metals by liquid metals is discussed. Calculated corrosion rates are compared with experimentally determined rates. It is concluded that diffusion controlled solution attack, although significant, may not under conditions of interest to reactor engineers be as ~~serious~~ as either inter-granular attack or chemically assisted mass-transport. The mechanism of intergranular attack, the thermodynamics of an example of chemically assisted mass-transport, the role of oxygen in sodium-stainless steel circuits, and methods of reducing mass-transport of iron are discussed. (auth)

NSA 14-1-587

- 1.200 Corrosion by Liquid Metals and Aqueous Solutions. P. R. Eisenberg, Paper from "Metals for Nuclear Reactors." American Society for Metals, Metals Park, Novelty, Ohio, 1959, p. 47-62.

Mass transfer and intergranular penetration in corrosion of Inconel and stainless steels by liquid metals. Reaction of impurities in liquid metal and purification techniques. Intergranular corrosion. Stress-corrosion cracking and galvanic corrosion of stainless steels by aqueous solutions at high temperatures. Static and dynamic testing. (R1, R2, R4, R6m:SS Ni-b)

Corrosion by liquid Hg

- 1.200 Willibald Machu (Universitate Cairo)  
Material and Corrosion Problems in the Reactor with Liquid Metals as Coolant  
Atomkern-Energie 3, 141-4 (1958) April (in German)

The last part in a series on material and corrosion problems in liquid metal cooled reactors is presented. The behavior of reactor materials in liquid bismuth, lead, and mercury is described. The corrosion mechanism of liquid metals is briefly discussed.

NSA 12:10093

- 1.200 METALLURGICAL DIVISION ANNUAL PROGRESS REPORT FOR PERIOD ENDING OCTOBER 10, 1957  
Dec. 13, 1957. Decl. with deletions Oct. 29, 1959. 247 p.  
Contract W-7405-eng-26. OTS (ORNL- 2422).

A series of Inconel-Na and Inconel-NaK forced circulation loops was operated to study mass transfer between Na and forced circulation loop of stainless steel, Incoloy, and Hastelloys B and W is discussed. A distillation system for the purification of Na is described.

NSA 14:1763

- 1.200 CF-57-2-146 (ORNL)  
A BRIEF REVIEW OF THERMAL GRADIENT MASS TRANSFER IN Na AND NaK SYSTEMS  
J. H. DeVan and J. B. West, February 11, 1957, 19 p.  
Contract W-7405-eng-26.

Mass transfer of structural materials in Na and NaK systems is solution rate limited. The limiting process has not been qualitatively or quantitatively confirmed for Inconel-Na or Inconel-NaK systems. Increasing the system wall temperature, above 1300°F, increases the amount of mass transfer. The effect of total  $\Delta T$  across the system on the amount of mass transfer was not determined.

CA 55:22945e

- 1.200 Dynamic Solution Rate Studies of Solid Metals in Liquid Metals by A. G. Ward (Atomic Energy Research Establishment, Harwell, Berks) and J. W. Taylor (Babcock and Wilcox Ltd., Renfrew)  
J. Inst. Metals 86, 36-42 (1957). Sept.

A study has been made of the kinetics of solution of solid Cu in liquid Pb and Bi under dynamic conditions in the temperature range 360 to 460°C, and the solution process is shown to conform to an expression of the form:  $n_t = n_0(1 - e^{-Kt(S/V)})$ , where  $n_t$  = solute concentration at time  $t$ ,  $n_0$  = saturation concentration at a fixed temperature.  $K$  = solution-rate constant,  $S$  = surface area of solid exposed,  $V$  = volume of solvent. This expression is similar to that which applies in nominally static tests. From the variation of  $K$  with temperature and velocity in the two systems studied, it is concluded that the effective rate controlling step in the dissolution process, under dynamic conditions, is the rate at which solute atoms are transferred from a saturated layer at the solid/liquid interface into the bulk of the liquid by turbulent and convective flow. The validity of a general relationship between the reduced concentration ( $n_t/n_x$ ) and the reduced time ( $t/t_x$ ) is established for dissolution at any temperature and under any dynamic condition;  $n_x$  is any fraction,  $x$ , of the saturation concentration  $n_0$ , and  $t_x$  is the time for the concentration to reach  $n_x$ . The use of this general relationship in interpolating complete concentration/time curves from limited experimental data is outlined. NSA 12:304

- 1.200 MASS TRANSFER IN LIQUID METALS  
Dunn, W. E. et al.  
A.I.Ch.E. J. 2, 184-9 (1956).

The rate of mass transfer was measured for solid metal shapes dissolving into mercury at room temperature. Sherwood numbers for horizontal tin, cadmium, zinc, and lead cylinders dissolving by natural convection agreed with Nusselt numbers for heat transfer in nonmetallic liquids at the same Rayleigh (Grashof x Prandtl) numbers. Dissolving of zinc tubes by mercury flowing turbulently within them agreed with heat transfer to nonmetals in tubes. Dissolving of random beds of lead spheres by mercury flowing through the bed agreed with similar nonmetal systems. It is concluded that mass transfer processes in liquid metals follow substantially the correlations for other fluids in heat or mass transfer, which with moderate safety factors may thus be used for at least preliminary design purposes.

- 1.200 TID-7526 (Pt. 1)  
Ames Lab., Ames, Iowa, Metallurgy Information Meeting,  
Ames Laboratory, Iowa State College, May 2, 3, and 4, 1956. 234p.

The topics included are: Nondestructive testing of EBWR fuel plates; Wetting temperatures of Eudl element components with Na and NaK; strengthening of Be for H High temperature use with BeO and Be<sub>2</sub>C dispersions; mechanical metallurgy of Zircaloy-3B; mechanical properties and corrosion behavior of Zircaloy-3B; constitution of U and the Pt metals; production of Th-Bi dispersions; preparation of radio-analysis of Kr and Xe and its use in diffusion experiments with Ag, preferred orientation in extruded Th rod; morphology of Zircaloy-2; microstructural appearance and identification of hydrides in Zr and Zircaloy-2-H<sub>2</sub> alloys; inspection of small diameter tubing by Eddy current methods; application of immersed ultrasonic technique for the inspection of small diameter tubes; corrosion and mass transfer by Li at high temperatures; and siliconizing of metals in liquid NaK. NSA 11:4464

- 1.200 KAPL-M-EGB-4  
ALPLAUS SURVEILLANCE PROGRAM. Progress Report No. 2. E. G. Brush  
Aug. 29, 1952. Changed from Official Use Only June 26, 1956. 9p.

Type-347 stainless steel and L nickel, considered as construction materials in the Alplaus heat-transfer system, were placed in the system to determine their corrosion resistance to liquid Na and NaK. The specimens were very resistant to attack by Na at 950°F and NaK at 850°F. There was no evidence of mass transfer between the stainless steel and Ni specimens. No transfer of mass from the hot to the cold zones occurred in one year.

- 1.200     Corrosion by Liquid Metals  
by Epstein, Leo F.,  
from "Progress in Nuclear Energy, Series 4, Technology and  
Engineering," Vol. 1, Edited by R. Hurst and S. McLain, McGraw-Hill,  
1956. Chapter 6, pp. 366-77. Epstein, Leo F.

The utilization of fused metals as heat transfer media in nuclear reactor systems has focused attention on the great advantages which can be attained by using these high thermal conductivity fluids, and has emphasized the importance of investigating the corrosion problems which they produce. Liquid metals are currently being used in mercury vapour boilers, in automobile and airplane valves, and elsewhere, and the study of corrosion effects with these substances goes back at least 30 years. The extremely high heat transfer requirements of nuclear reactors has resulted in an intensive and accelerated investigation of these effects over the last 10 years, particularly with liquid sodium and Na-K alloys. These investigations have been carried out in the U.S. at a number of the national laboratories of the USAEC, several universities and a large number of industrial organizations.

Experimental techniques for determining corrosion rates in static (isothermal) and dynamic systems, where there is a  $\Delta T$ , are described, and details of the results of experience with mercury, sodium and Na-K alloys are presented. The behaviour of materials in lithium, lead, bismuth and gallium are also discussed briefly.

There appear to be two basic processes involved in the phenomenon of corrosion by liquid metals (1) chemical reaction and (2) solution. The latter in turn may be divided into two classes (2a) where the rate of attack is determined by the heterogeneous diffusion of solute atoms across the solid-liquid interface ("solution rate limited") and (2b) where the rate of corrosion is fixed by the homogeneous diffusion of the solute through the solvent fluid ("diffusion limited"). Equations for the dependence of these various kinds of corrosion phenomena on temperature, fluid flow velocity, the geometry of the system and similar factors are presented.

A few special topics in liquid metal corrosion are also touched upon, namely: (a) heterometallic effects; (b) welding and diffusion bonding; (c) carburization and nitridification; and (d) corrosion of compounds and non-metallic materials.

- 1.200     Gurinsky, D. H., The Behavior of Materials in Aggressive Liquid Metals from IMD Special Report Series No. 2 - Nuclear Metallurgy 2-20-56'

With reference to Hg, Pb, and Zn, there are six processes of mass transfer: 1) dissolution of metal into quiet boundary layer, 2) diffusion of dissolved metal into moving stream from a boundary layer, 3) transport by the moving stream, 4) nucleation of metal crystals in the stream, 5) growth of crystallites in the boundary layer accompanied by sintering, 6) transport of nuclei or crystallites into the boundary layer. Three variables of dynamic testing are: 1) alloying elements of test material, 2) additions to liquid, 3) time and temperature.

Addition agents can inhibit attack by formation of an insoluble layer of high stability on a solid surface, Zr, Ti, Cr, etc., carbides and nitrides.

Mg acts as oxidizing agent which conserves others.

Intermetallic compounds have the highest attack resistance.

Bi can be deoxidized by bubbling purified  $H_2$  through filters.

- 1.200 Interactions Between Solid and Liquid Metals and Alloys  
Eldred, V. W.  
Atomic Energy Research Estab. (Gt. Brit.) X/R 1806, 220pp. (1955).

An investigation was made of the corroding effect of liquid Hg on Cr, Fe, and Co; of liquid K on Mg, Ag, Al, W, Cr, Cu, Fe, Co, and Ni; of liquid Na on Mg, Ag, Al, W, Cr, Cu, Fe, Co, Ni, and some ferrous and non-ferrous alloys; of Sn on Cr and ferrous and non-ferrous alloys; of Bi on Al, Ag, W, Cr, Cu, Fe, Co, and ferrous and non-ferrous alloys; of Cd on Cr, Fe, Co, and ferrous and non-ferrous alloys; of Pb on Ag, Al, W, Cr, Cu, Fe, Co, Ni, and ferrous and non-ferrous alloys; and Zn on ferrous and non-ferrous alloys. The tests were carried out at temperatures up to 550°C for periods of contact up to 300 hours. The filtered liquid metal was forced into glass tubes containing clean bars of the solid metal, under controlled atmosphere. Previous work, recent work done elsewhere, and the author's results were considered to discuss the characteristics of metals and alloys showing a high corrosion resistance to liquid metals. The experimental evidence indicated that inert systems have a difference of at least 50 in the Hildebrand solubility parameters of the 2 components. The rate of attack by solution of the solid in the liquid was considered in detail for the first time. Five possible processes for the attack of a liquid metal on a solid metal were presented. 200 references.

- 1.200 Columbia Univ.  
MASS TRANSFER IN LIQUID METAL AND FUSED SALT SYSTEMS; THIRD QUARTERLY PROGRESS REPORT, by Charles F. Bonilla, Bernard Gross, Fred Kant, R.N. Roy Choudhery, and N. S. Shaikhmahmud. Mar. 1, 1952. (NYO-3088)

A detailed diagram is presented of the recently completed equipment for measuring mass transfer between two liquid metals in a spray column; the first series of runs is outlined. Brief descriptions of the apparatus, procedure, and results of the first run are given for studies of mass transfer between a packed bed (Pb shot) and a liquid metal (Hg). The experimental results of Samarin and Shvartsman (Izvest. Akad. Nauk SSR Otdel. Tekh. Nauk, 1649-51 (1927) on the diffusivity of various metals in Hg are tabulated; the calculated values have been recomputed, and the ratios of experimental to calculated values are given. The agreement is quite good for the alkali and alkaline earth metals, but for the other metals the Stokes-Einstein equation prediction is only about half of the observed diffusivity. Results of a literature survey on velocity of droplets in a spray column are summarized for streamline and turbulent flow.

NSA 6:2909

- 1.200 Mass Transfer in Liquid Metal and Fused Salt Systems; Second Quarterly Progress Report. Charles F. Bonilla. Dec. 1, 1951.  
11p. Contract AT(30-1)-1100. (NYO-3087). Dep.

The line of attack being followed in current investigations of the following problems is outlined: mass transfer between a bed of particles and a liquid metal flowing through it, mass transfer between two liquid metals in a spray column, velocity of droplets of liquid metal or salt in a spray column, and diffusion coefficients in liquid metals. No experimental data are given.

- 1.200 ANL-4417  
Resistance of Materials to Attack by Liquid Metals  
L. R. Kelman, W. D. Wilanson, F. L. Yaggee. 1949

Na and NaK corrosion results are included. Mass transfer problem leading to plugging of loops were observed at high temperatures and when oxygen content was high in Na or NaK.



- 1.200 Columbia Univ.  
MASS TRANSFER IN LIQUID METAL AND FUSED SALT SYSTEMS: FIRST  
QUARTERLY PROGRESS REPORT, by Charles F. Bonilla. Sept. 1, 1951, 8p.  
(NYO-3086)

In this first quarterly progress report a brief summary is given of mass-transfer studies carried out on an unsponsored basis prior to the date of the AEC contract. Natural-convection mass transfer was investigated by depressing horizontal cylinders of Pb, Zn, Cd, and Sn beneath the surface of a Hg bath; the change in buoyant force due to dissolving of the cylinder was measured as a function of time. The four mass-transfer cases agreed moderately well among themselves, and a reasonable correlation was found with the heat-transfer case. The poorest agreement was with the Pb points, which averaged about 65% of the heat-transfer correlation. Forced-convection mass transfer from the inner surface of a cylindrical tube to the fluid flowing within the tube was also investigated with Hg as the flowing fluid. The limited data obtained agree rather well with curves previously reported for nonmetals. (N.S.A. Vol. 6-2362).

---

1.210 RATE CONTROLLING STEPS

- 1.210 NAA-SR-6306  
J. F. Nejedlik, J. J. Owens  
SNAP II POWER CONVERSION SYSTEM - TOPICAL REPORT #14 - MERCURY  
MATERIALS EVALUATION AND SELECTION

Steels, high temperature alloys and refractory metals were screened to evaluate corrosion resistance for long service in a boiling Hg system. High Mn or Ni containing alloys were among the least resistant materials. The Co base Haynes 25 was resistant for a limited time at 900°F after which an increased corrosion rate was observed.

A study of corrosion kinetics which led to excessive sludge deposition was made. The change of temperature coefficient for mass transfer for many of the structural alloys was proposed to indicate a change of mechanism above 700°F. Diffusion controlled corrosion and crevice attack were suggested from the results.

- 1.210 The Effect of Molten Alkali Metals on Containment Metals and Alloys  
at High Temperatures  
M. F. Amateau, May 1962, DMIC Report 169

Corrosion of containment materials is the most serious problem in liquid-metal systems. Most of the high-temperature engineering metals such as refractory metals, are sufficiently resistant to liquid sodium and NaK to be useful up to about 1600°F. The most important factor in the corrosion of these materials under given conditions of temperature and flow rate is the oxygen content of the sodium. The refractory metals and alloys are particularly susceptible to attack by sodium containing excessive amounts of oxygen.

Potassium, rubidium, and cesium are somewhat less corrosive than the other alkali metals. The refractory metals and alloys are little affected by these liquid metals.

Sodium and potassium can cause degradation of mechanical properties of containment materials, depending on the amount of oxygen and nitrogen found in the respective liquid metals. Also, the sliding and bearing properties of metals are generally affected adversely by the presence of pure molten metals.

- 1.210 Liquid Metal Corr. Mechanisms, J. R. Weeks, C. J. Klamut and D. H. Gurinsky (USAEC) IAEA Preprint CN-13/11 53p.

To be published in Proceedings of the IAEA Conference on the Corr. of Reactor Materials held in Salzburg 4-9 June, 1962

The corr. of solid metals by liquid metal coolants & fuels is a complex process. Kinetics of dissolution and pptn of solid metals in liq metal, and complex multicomponent solubilities and their temp coefficients are both part of the corrosion mechanism. In addition, non-metallic impurities (O, N, C) affect both the kinetics and solubilities. An atom of a solid metal dissolves in the liq metal by breaking its bonds with its neighbor like-atoms and forming new ones with liq atoms. This process is dependent on structure of the solid-liquid interface. The dissolved atom then migrates perhaps with its "salvation shield," through the relatively quiet liquid adjacent to the solid metal into the main body of coolant. This migration is a function of fluid flow. The exchange of electrons that occurs during dissolution of the solid metal is not well understood; it is likely to influence both the dissolution and diffusion processes, as indicated by electro-diffusion experiments. The magnitude and temp. coefficients of the solubilities of solid metals in liquid metals cannot be predicted by the present theories of liquid alloys. They appear to depend upon the band structure of the liquid alloy and upon the relative atomic diameters of the solute and solvent atoms in the liquid alloy. Magnetic susceptibility, elect. resistivity and alloy density measurements are useful guides in advancing the theory. Precise experimental liquidus measurements of very dilute alloy systems are at present the most reliable means of interpreting the corrosion mechanisms in a given system. O, N, and C in many cases catalyze corrosion by liq. metals. They both accelerate the dissolution rate and increase the solubility of many solid metals in alkali liquid metals presumably by forming soluble complexes. Zr and Ti additions to the liquid metal inhibit corrosion of steels by Pb, Bi, and Hg by reacting with C and/or N in steel to form surface deposits of carbides and/or nitrides which are a barrier to dissolution. Examples are cited from the literature that illustrate the kinetic and thermo-dynamic processes occurring during liquid metal corrosion.

NSA 15:22155

- 1.210 TID 3544  
Isothermal Mass Transfer in Liquid Metals. A. K. Covington and A. A. Woolf. Reactor Technol. 1, 35-41(1959) Apr.

NSA 13:14563

- 1.210 J. W. Taylor, Babcock and Wilcox Co., Ltd.  
Mass Transfer in Liquid Metal Systems. 2. Isothermal Transfer. Nuclear Power 3, 101-5 (1958) Mar.

Isothermal mass transfer is a second type of transfer process in liquid metals, the other being thermal-gradient transfer. In general it involves the transfer of a component from a source via a liquid metal solution to a reaction site usually near a second component, the driving force for the transfer being a free energy change of reaction; the solubility of the transferring in the liquid metal need only be very slight. The form of the reaction product and its location depend upon the phase relationships between the transferring component and the reactant, and between the latter and the liquid metal. The kinetics of the transfer is complex and is influenced by such factors as system geometry, form of reaction product, and source of transferring component. Surface films may seriously influence the transfer in so far as they may affect the source of the transferring component and also the reaction state.

NSA 12:6596

1.210 Static and Dynamic Corrosion and Mass Transfer in Liquid Metal Systems

Epstein, Leo F. (Knolls Atomic Power Lab., Schenectady, N. Y.)  
Chem. Eng. Progr. Symposium Ser. 53, No. 20, 67-81 (1957).

In many systems involving liquid metals, corrosion of a solid exposed to the fluid is by simple solution. In a static isothermal assembly the rate of corrosive attack is determined by the solution rate. The value of this parameter depends on whether the rate-determining step is (1) the diffusion of the solute through the liquid or (2) transfer of the solute through a solid film or some product of chemical reaction at the solid-liquid interface. In dynamic corrosion, such as is encountered in heat-transfer loops, where parts of the system are at different temperatures and the fluid flows continually from the hot to the cold zone, different expressions are obtained for the corrosion rate, depending on whether mechanism 1 or 2 is more important. These results are examined for a few solid-liquid metal systems, and quantitative relations capable of yielding order-of-magnitude agreement with experiment are obtained. The material dissolved in the hot zone of a heat-transfer loop tends to deposit out of solution in the cold zone, resulting in an overall transport of material. Factors influencing this mass transfer rate are examined. The effects of minor impurities in the solvent in accelerating and inhibiting corrosion are discussed.

CA 51:16260

1.210 AERE-M/R-2113

Ward, A. G. et al.

Atomic Energy Research Establishment (Gt. Brit.)

Dynamic Solution-Rate Studies of Solid in Liquid Metals.  
January 1957.

A study has been made of the kinetics of solution of solid copper in liquid lead and bismuth under dynamic conditions in the temperature range from 360 degrees C to 460 degrees C. The solution process is shown to conform under dynamic conditions to an expression of the form:

$$n_t = n_o (1 - e^{-K(S/V)t})$$

where  $n_t$  = solute concentration at  $t$ ,  $n_o$  = saturation concentration at a fixed temperature,  $K$  = solution rate constant,  $S$  = surface area of solid exposed,  $V$  = volume of solvent. This expression is similar to that found to apply in nominally static tests. From the variation of  $K$  with temperature and velocity in the two systems studied, it is concluded that the effective rate controlling step in the dissolution process, under dynamic conditions, is the rate at which solute atoms are transferred from a saturated layer at the solid-liquid interface with the bulk of the liquid by turbulent and convective flow. The validity of a general relationship between the reduced concentration  $n_t/n_o$  and the reduced time  $t/t_x$  is established for dissolution at any temperature and under any dynamic condition;  $n_x$  is any fraction of the saturation concentration  $n_o$  and  $t_x$  is the time for the concentration to reach  $n_x$ . The use of this general relationship in interpolating complete concentration-time curves from limited experimental data is outlined. Title Announcement Bull. U58-17 p. 3124.

- 1.210 Dynamic Solution Rate Studies of Solid Metals in Liquid Metals  
A. G. Ward (Atomic Energy Research Establishment, Harwell, Berks)  
and J. W. Taylor (Babcock and Wilcox Ltd., Renfrew)  
J. Inst. Metals 86, 36-42 (1957). Sept.

A study has been made of the kinetics of solution of solid Cu in liquid Pb and Bi under dynamic conditions in the temperature range 360 to 460°C, and the solution process is shown to conform to an expression of the form:  $n_t = n_0(1 - e^{-Kt(S/V)})$ , where  $n_t$  = solute concentration at time  $t$ ,  $n_0$  = saturation concentration at a fixed temperature.  $K$  = solution-rate constant,  $S$  = surface area of solid exposed,  $V$  = volume of solvent. This expression is similar to that which applies in nominally static tests. From the variation of  $K$  with temperature and velocity in the two systems studied, it is concluded that the effective rate controlling step in the dissolution process, under dynamic conditions, is the rate at which solute atoms are transferred from a saturated layer at the solid/liquid interface into the bulk of the liquid by turbulent and convective flow. The validity of a general relationship between the reduced concentration ( $n_t/n_x$ ) and the reduced time ( $t/t_x$ ) is established for dissolution at any temperature and under any dynamic condition;  $n_x$  is any fraction,  $x$ , of the saturation concentration  $n_0$ , and  $t_x$  is the time for the concentration to reach  $n_x$ . The use of this general relationship in interpolating complete concentration/time curves from limited experimental data is outlined. NSA 12:304

## 1.220 DIFFUSION CONTROLLED EFFECTS

- 1.220 LIQUID METAL CORROSION MECHANISMS  
J. R. Weeks, C. J. Klamut and D. H. Gurinsky  
U.S. Atomic Energy Commission, Washington, D. C., USA  
Conference on Corrosion of Reactor Materials, Salzburg, June 1962,  
International Atomic Energy Agency

An atom of a solid metal dissolves in a liquid metal by breaking its bonds with its neighbor like-atoms and forming new ones with liquid atoms. This process is dependent on the structure at the solid-liquid interface. The dissolved atom then migrates, perhaps with its "solvation sheath," through the relatively quiet liquid adjacent to the solid metal into the main body of coolant. This migration is a function of the liquid flow. The exchange of electrons that occurs during dissolution of the solid metal is not well understood; it is likely to influence both the dissolution and diffusion processes, as indicated by electro-diffusion experiments.

The magnitude and temperature coefficients of the solubilities of solid metals in liquid metals cannot be predicted by the present theories of liquid alloys. They appear to depend upon the atomic structure of the liquid alloy, and upon the relative atomic diameters of the solute and solvent atoms in the liquid alloy. Magnetic susceptibility, electrical resistivity, and alloy density measurements are useful guides in advancing the theory. Precise experimental liquidus measurements of very dilute alloy systems are at present the most reliable means of interpreting the corrosion mechanisms in a given system.

- 1.220 NAA-SR-6306  
J. F. Nejedlik, J. J. Owens  
SNAP II POWER CONVERSION SYSTEM - TOPICAL REPORT #14 - MERCURY  
MATERIALS EVALUATION AND SELECTION

Steels, high temperature alloys and refractory metals were screened to evaluate corrosion resistance for long service in a boiling Hg system. High Mn or Ni containing alloys were among the least resistant materials. The Co base Haynes 25 was resistant for a limited time at 900°F after which an increased corrosion rate was observed.

A study of corrosion kinetics which led to excessive sludge deposition was made. The change of temperature coefficient for mass transfer for many of the structural alloys was proposed to indicate a change of mechanism above 700°F. Diffusion controlled corrosion and crevice attack were suggested from the results.

- 1.220 ER-4103  
THE SNAP II POWER CONVERSION SYSTEM TOPICAL REPORT No. 7.  
MERCURY MATERIALS EVALUATION AND SELECTION  
(TID-11,307)  
J. J. Owens et al., October, 1960. 143p. Thompson-Ramo-  
Wooldridge, Inc., Cleveland, Ohio.

This report presents the results of a two-year material compatibility study and discusses the corrosion mechanisms involved in a system in which mercury is the working fluid. Includes 35 references and 11 bibliographies. (AGN Lib 2-5632)

NSA 15:21096

- 1.220 AEC TR2949 Diffusion of B, C & N into Transition Metals of IV, V, & VI Groups of Periodic Table

Studies of B and C diffusion into Ti, Zr, Nb, Ta, Mo and W were made on specimens of .... and 99.94% Nb .... Before saturating with .... carbon (calcinated C black 99.8% C) the specimens were annealed to relieve internal tensions. X-R analysis of diffusion showed layer formations of .... Nb<sub>2</sub>C<sub>1</sub>. These data were confirmed by chem. analysis coordinated with mean content in the diffusion layer determined from the concentration of C .... on boundaries of corresponding phases. A table of diffusion eg. is given. Activation energies of .... C .... diffusion into transition metals of IV, V and VI groups of the periodic system and the relation of active heat to the scattering of metal atoms are discussed.

NSA: 11-11229

- 1.220 CF 57-7-115 ORNL  
Some Calculations of Diffusion Controlled Thermal Gradient Mass Transfer, J. J. Keyes, Jr. July 22, 1957. Decl. Oct. 9, 1959. 43p. Contract (W-8405-eng-26). OTS.

Calculations are presented of the amount of mass transfer to be expected in liquid alkali metal-Ni alloy systems for two assumed diffusion mechanisms. In one, the boundary layer is assumed saturated and the transfer rate is limited by the rate of diffusion of solute into the liquid. In the other, the mass transfer rate is assumed to be limited by the diffusion rate of a component of the solid alloy to the solid surface. It is concluded that a more general hypothesis is needed.

- 1.220 Isothermal Mass Transfer in Liquid Metals  
Taylor, J. W. and Ward, A. G.  
Atomic Energy Research Establishment (Gt. Brit.)  
July 1957, 16p. illus. tables  
AD 158 887 Div. 4, 17, AERE M/R 2296; HX 3172 TAB 1 Sept. 1959:4301

The available information on the transfer of metallic and metalloid elements by liquid metals under isothermal conditions is considered. A study of the transfer of copper via liquid lead to solid aluminum is reported and information presented on the rate determining steps and on the effect of a number of experimental variables. The isothermal transfer of a component via a liquid metal is motivated by the change in free energy accompanying the removal of a component from the liquid phase by reaction with a solid. The form of the deposit, whether adherent to the solid or not, depends upon the phase relationships between the transferring component and the reacting solid and between the latter and the liquid metal. The kinetics of the process are dependent on the geometry of the system and on the diffusion coefficients of the components in the phase formed at the reacting solid surface. Surface films, either metallic or non-metallic, can have a pronounced effect on the extent of the transfer.

1.220 Static and Dynamic Corrosion and Mass Transfer in Liquid Metal Systems

Epstein, Leo F. (Knolls Atomic Power Lab., Schenectady, N. Y.)  
Chem. Eng. Progr. Symposium Ser. 53, No. 20, 67-81 (1957).

In many systems involving liquid metals, corrosion of a solid exposed to the fluid is by simple solution. In a static isothermal assembly the rate of corrosive attack is determined by the solution rate. The value of this parameter depends on whether the rate-determining step is (1) the diffusion of the solute through the liquid or (2) transfer of the solute through a solid film or some product of chemical reaction at the solid-liquid interface. In dynamic corrosion, such as is encountered in heat-transfer loops, where parts of the system are at different temperatures and the fluid flows continually from the hot to the cold zone, different expressions are obtained for the corrosion rate, depending on whether mechanism 1 or 2 is more important. These results are examined for a few solid-liquid metal systems, and quantitative relations capable of yielding order-of-magnitude agreement with expt. are obtained. The material dissolved in the hot zone of a heat-transfer loop tends to deposit out of solution in the cold zone, resulting in an overall transport of material. Factors influencing this mass transfer rate are examined. The effects of minor impurities in the solvent in accelerating and inhibiting corrosion are discussed.

CA 51:16260

1.220 Some Internal Friction Studies in Columbium, R. W. Powers and M. V. Doyle (G E Co., Schenectady), J. Metals 9, 1285-8, Oct. 1957.

Carbon has been found to diffuse in Nb at a slightly more rapid rate than  $N_2$ . At 1 cps that internal friction peak which arises from stress-induced ordering of C in Nb is found at  $268^\circ\text{C}$  while  $N_2$  peak occurs at  $285^\circ\text{C}$ . The diffusion coeff. are  $D = .0046 \exp. (-33,300/RT)$  for C in Nb and  $D = 0.0072 \exp. (-34,800/RT)$  for  $N_2$  in Nb. The carbon peak in Nb is very unstable, the height declining rapidly with time in contrast to the  $N_2$  peak. The ratio of height of  $N_2$  peak to cone of  $N_2$  in solid sol. (expressed in wt. %) was found to be 0.33 in good agreement with previous work. The internal friction in high purity  $N_b$  was found to be sensitive function of strain amplitude at which the damping was measured.

NSA 12-1421

---

1.230 EFFECT OF TEMPERATURE GRADIENTS

1.230 MND-P-2382  
SNAP I POWER CONVERSION SYSTEM MATERIALS DEVELOPMENT. TAPCO (ER-1057) June 20, 1960, V. F. Hambor and J. J. Owens

Metallic materials were investigated to determine their resistance to corrosive attack by Hg and the effect of mass transfer due to temperature and concentration gradients existing in the system. Materials evaluated included the refractory metals, carbon steels, and the 300 and 400 series stainless steels. As a result of the metallic materials effort, it was concluded that the corrosion contaminants generated produce a more severe problem than the loss of structural material. (AGN Lib. 1-978)

1.230 SOME STUDIES OF CORROSION IN LIQUID METAL  
H. M. Finniston (AERE) p. 189-96 of "Australian Atomic Energy Symposium, 1958".

The kinetics of solutions in liquid metals were shown to be analogous to the kinetics of reaction in chemical systems based on aqueous and non-aqueous solvents and in most cases studied resembles the transfer of heat across a solid-coolant interface. Differential solubility of the solute with temperature of the liquid metal was found to be responsible for thermal gradient mass transfer. The precipitation process in mass transfer did not seem to be the rate controlling step.

NSA 14:1209

1.230 Corrosion in Liquid Metal

Finniston, H. M.

At. Energy Research Estab., Harwell, England

Proc. Australian At. Energy Symposium 1958, 189-96

CA 53:16898e

Research on the soln. of the solid metal in the liquid phase is described and the theory is discussed. The mechanism of mass transfer under a thermal gradient leading to plugging in a loop is discussed. This effect is reduced in a Croloy steel-liquid Bi loop by the formation of a Zr nitride surface film. Mass transfer is appreciable with sol. slurries, but does not affect insol. slurries. Insol. slurries require a dispersing medium. Isothermal mass transfer is discussed.

1.230 PB-131065

ANALYSIS OF TEMPERATURE COEFFICIENTS OF SOLUBILITY IN DILUTE

LIQUID METAL SOLUTIONS, by Strauss, S. W. et al.,

U. S. Naval Research Laboratory, June 1957. 23p. graphs

Temperature coefficients of solubility taken from the literature were compared with (a) electronegatives of solvent and solute, and (b) relative atomic sizes of solvent and solute, in order to identify the fundamental factor or factors which determine the temperature coefficient of solubility of a solid metal in a second liquid metal. U.S. Gov. Res. Reports Vol. 28, No. 3, page 153.

1.230 J. W. Taylor, Babcock and Wilcox Co., Ltd.

Mass Transfer in Liquid Metals Systems. I. Thermal Gradient Transfer.  
Nuclear Power 3, 53-7 (1958) Feb.

Mass transfer in liquid metal systems occurs by thermal gradient transfer of isothermal transfer. In liquid-metal systems having a temperature differential, mass transfer of the container material may result in failure of the hot limb component or stoppage of the flow because of precipitation in the cold limb. Experimentally this transfer may be studied in thermal or forced convection conditions. The basic steps of the transfer process are solution of the container components and precipitation at the cold limb. The kinetics of dissolution and the parameters influencing it have been studied and the results are reviewed. Less is known about the kinetics of the second process.

NSA 12:5996

1.230 A BRIEF REVIEW OF THERMAL GRADIENT MASS TRANSFER IN SODIUM AND NaK

SYSTEMS J. H. DeVan and J. B. West. Feb. 11, 1957. 19p. Contract W-7405-eng-26 OTS

Oak Ridge National Lab., Tenn. CF-57-2-146

The fact that material transport does occur under conditions of finite temperature difference in a flowing molten metal system was established. The rate mass transfer was thought to be either diffusion limited or solution rate limited. It is believed that the mass transfer of structural materials in Na or NaK systems is solution rate limited. The limiting process has not been qualitatively or quantitatively confirmed for the Inconel-Na or Inconel-NaK system. Increasing the maximum system wall temperature increases the amount of mass transfer, at least above 1300<sup>o</sup>F. The effect of the total temperature difference across the system on the amount of mass transfer was determined. (W.L.H.)

NSA 14:32691

## 1.240 GEAP-4080

SODIUM-COOLED REACTORS PROGRAM. Fast Ceramic Reactor Development Program, Fourth Quarterly Report July - September, 1962.  
F. J. Leitz. January 31, 1963. Contract No. AT(04-3)-189

Four sodium logging capsules were irradiated during April - June 1962 and results reported in the third quarterly report (GEAP 3981). The fifth Na logging capsule was loaded with NaK in place of Na as a heat transfer medium so the specimen could be taken to full power in one step instead of holding at low power until the Na had melted. Na-UO<sub>2</sub> compatibility is being tested in a pumped loop to 1050°F. (AGN Lib. 3-1697)

1.240 Effects of Radiation on Metallic Corrosion

J. J. Stobbs (Central Electricity Gen. Board, Nuclear Labs, Berkeley, Gloucester, England)  
Met. Rev. 7:95-131 (1962)

A review on the radiation effects on metallic corrosion is presented. The problem of expressing the rate of irradiation is considered briefly. Radiation effects on the metal itself, on the protective layer, and on the corrodent are discussed in detail. The corrodents considered include gases, aqueous solutions, organics, liquid metals, and fused salts (D.L.C.)

NSA 16:27570

1.240 NAA SR5363 Corrosion and Radioactive Activity Transfer in the SRE Primary Sodium System, Oct. 30, 1961.

An evaluation extending over 2 years was made of primary system Na and of stainless steel, and Zr and Be specimens exposed in hot and cold legs of a bypass loop in primary system of Sodium Reactor Experiment (SRE). The metal specimens were checked for physical property changes and for radioactivity transfer of hot to cold leg surface. Stainless steel tabs underwent no significant micro-structural changes. However, the Zr specimen showed varying degrees of hydriding, generally characterized as moderate. Severe hydriding of one Zr tab resulted in serious embrittlement. Low O<sub>2</sub> pickup on Zr specimen verified hot-trap O<sub>2</sub> control of SRE primary system Na to less than 10 ppm, with a correspondingly low amount of oxidation of Zr moderator cans.

NSA 16:1191

1.240 NUCLEAR MAGNETIC RESONANCE IN ALKALI ALLOY SYSTEMS NaK AND NaRb

L. Rimai and N. Bloembergen (Harvard Univ., Cambridge, Mass.) Phys. and Chem. Solids 13, 257-70 (1960) June. (In English).

The Knight shift K in liquid NaK and NaRb systems is a linear function of the relative Na concentration 1-C. ...An interpretation in terms of the scattering theory of conduction electrons is given ...The experiments show that nuclear magnetic resonance is particularly well suited to determine phase diagrams of alkali metal systems.

NSA 14:22067

1.240 Effects of Radiation on Some Corrosion Resistant Fuel Alloys  
J. H. Kittel, K. F. Smith (May 1960) ANL-56401.240 Effects of Neutron Irradiation in Non-Fissionable Metals and Alloys  
International Atomic Energy Agency, Bibliography, Series No. 6 (1962)1.240 Symposium on Radiation Effects and Radiation Dosimetry  
ASTM - Philadelphia, Pennsylvania - 63rd Annual Meeting, June 24, 1960.  
ASTM Spec. Tech. Pub. #268.1.240 Irradiation Effect on the Surface Reaction of Metals

T. D. Carpenter, GA-1093 (15 Dec. 1959)  
Rad. Dam. Studies Program ETR Loop Mat. Progress Rep. #2  
M. S. Robinson (16 Sept 1957) IDO-16409



- 1.240 CORROSION OF METALS IN AN EXPERIMENTAL CHANNEL IN THE IRT REACTOR  
A. V. Byalobzhetskii, V. D. Val'kob. Atomnaya Energiya, Vol. 10, No. 5, pp. 524-5. May 1961. Submitted April 8, 1960.
- 1.240 The Effect of Nuclear Radiation on Structural Metals  
REIC Report #20 (Sept 1961)
- 1.240 The Effect of Nuclear Radiation on Structural Metals  
DMIC Report #166 (Sept 1961) F. R. Shober, BMI  
Little or no effect of radiation on corrosion of pure metals
- 1.240 Irradiation and Temperature History of SRE Dummy Fuel Element Cans  
NAA-SR-Memo-5437 (June 1960)
- 1.240 LIQUID METAL LOOPS IRRADIATED IN THE ORNL GRAPHITE REACTOR AND THE LITR  
W. W. Parkinson and O. Sisman. June 1, 1959. 35 p. Contract W-7405-eng-26. \$1.25 (OTS). ORNL-2630.

Liquid alkali metals were circulated in a series of structural alloy loops under reactor radiation at high temperature. The first of these loops was a lithium-stainless steel (type 316) system, and the remainder were sodium-Inconel. The lithium-stainless steel loop operated at 1000°F with a flow of 2 fps for 160 hr, receiving a fast neutron dose of  $3 \times 10^{16}$  neutrons/cm<sup>2</sup>. Three of the sodium loops operated at 1500°F in the in-pile section and 1100°F at the pump cell, with flows of 1 to 1.5 fps; the duration of operation ranged from 101 to 285 hr to give fast neutron exposures of 1.8 to  $4 \times 10^{16}$  neutrons/cm<sup>2</sup>. The fourth sodium loop incorporated a stress-corrosion specimen stressed at 1500 psi. This loop operated between 1070 and 1270°F for 159 hr at a flow of 1 fps through the specimen. The dose ranged up to  $5 \times 10^{16}$  thermal neutrons/cm<sup>2</sup> and  $2 \times 10^{18}$  fast neutrons/cm<sup>2</sup> at the in-pile end of the specimen. In all loops, corrosion, if any, was less than 0.0005 in. No effect of radiation other than radioactivation was found. Mass transfer and metallurgical processes attributable to the operating temperatures were observed. (auth)

NSA 13:13541

- 1.240 IGR-TN/W-862 UNCLASSIFIED  
United Kingdom Atomic Energy Authority. Industrial Group H. Q., Risley, Lancs, England.  
The Adhesion of Niobium and Stainless Steel Surfaces During Irradiation in Sodium  
Howd, D.  
Apr. 10, 1958. 12 p.

Contacts consisting of stainless steel-niobium, stainless steel-stainless steel, and niobium-niobium were irradiated for 1280 hours in sodium at about 600°C under a load to give 800 psi at the interfaces. No signs of adhesion or pressure-welding were detected on subsequent examination. (auth)

- 1.240 FORCED CONVECTION LIQUID METAL IN-PILE LOOP HOT SPOT ANALYSIS (TID - 12272)  
D. B. Vasallo (CANEL) Feb. 25, 1959. Decl. Sept. 18, 1959. 21 p. (TIM - 578)

The results of hot-spot and hot-channel analyses performed on the Pratt and Whitney forced convection liquid metal in-pile loop (PW - 19) are reported.

NSA 15:13482

- 1.240 TID-3305  
DISSOLUTION AND DISTRIBUTION BY LIQUID SODIUM OF ACTIVATED TYPE 347 STAINLESS STEEL  
A. M. Saul, Mar. 15, 1954. Decl. Mar. 19, 1957. 26 p. (TID-10021)

The distribution by Na of the radioactive elements of Type 347 stainless steel was studied under dynamic conditions using convection-diffusion capsules operating between 300 and 700°C. The nuclides identified as depositing on the initially inactive walls of these capsules are Ta<sup>182</sup>, Fe<sup>59</sup>, Co<sup>60</sup>, Cr<sup>51</sup>, and Mn<sup>54</sup>. Deposition of these activities does not seem to be a function of capsule wall temperature alone. It was found that the presence of O<sub>2</sub> greatly accelerates the transfer of activity.

- 1.240 Compatibility of Reactor Materials in Flowing Sodium  
Davis, M. and Draycott, A.  
United Kingdom Atomic Energy Authority Culcheth, Lance,  
England. Atomic Energy Commission, Australia  
A/CONF. 15/P/25 36p.  
NSA 13:6764 page 901

The validity of various types of compatibility tests is briefly discussed, particularly the severe limitations of static experiments. Differences expected between sodium and NaK are noted. A typical corrosion test rig is described and its application to radioactive mass-transfer measurements discussed. The types of specimens used, the measurements made before and after tests, the assessment of the results, and their correlation with reactor circuits are detailed. The variables studied include the temperature of the specimen, the velocity of the liquid metal over the specimen, the oxide level in the liquid metal and the initial state of the specimen. The materials investigated include stainless steel, various ferritic steels, zirconium, niobium, vanadium, uranium, and fission products, thorium, and beryllium. Niobium and vanadium were studied in greatest detail.

- 1.240 BEHAVIOR OF PARTICLES OF U, UO<sub>2</sub> AND UC<sub>2</sub> IN A VERTICAL TUBE THROUGH WHICH LIQUID SODIUM IS FLOWING  
C.L.W. Berglin. June 1956. 17 p. (AAEC/E-3) Atomic Energy  
Commission Research Establishment, Lucas Heights, New South Wales,  
Australia.

The relation between the particle velocity and the fluid velocity in a vertical tube without making any assumptions as to the apparent viscosity of the suspension of particles in liquid Na is examined. The theory and calculations method is developed for suspensions of U, UO<sub>2</sub> and UC<sub>2</sub> in liquid Na in the temperature range 200 to 800°C.

NSA 13:12250

- 1.240 THE RADIATION INDUCED CORROSION OF BERYLLIUM OXIDE IN SODIUM AT 1500°F CF-53-12-12  
W. E. Brundage and W. W. Parkinson  
ORNL, Dec. 3, 1953, Decl. Dec. 6, 1959, 9 p. OTS

Beryllium oxide specimens of various densities, immersed in sodium, were irradiated in the LITR for 328 hrs at 1500°F plus 110 hrs at 750°F. The exposure at the higher temperature was about  $1.8 \times 10^{19}$  thermal nvt and  $0.9 \times 10^{19}$  fast. Control specimens were subjected to the same heat treatment in sodium and the average weight loss was found to be 0.0007 g (0.037%) with no significant difference between the irradiated and control groups. The surface-to-volume ratio was roughly  $2.5 \text{ cm}^2/\text{cm}^3$ .

NSA 15:7701

- 1.240 NAA-SR-258  
North American Aviation, Inc., Downey, California  
Compatibility of Sodium, Graphite and Stainless Steel by  
Coultras, T. A. and R. Cygan July 8, 1953. Decl. March 5, 1957.  
Contract AT-11-1-GEN-8 30 p.

Experiments have been performed to determine the compatibility of graphite and molten Na under various conditions. Effects such as corrosion, thermal shock, dimensional changes and penetration of Na into the graphite pores were investigated. Significant corrosive attack on the graphite was noted only in the presence of carburization of the container material. Stainless steel showed no appreciable carburization below 550°C, but carburization was found at temperatures of 600°C and higher. Carburization of Zr was observed only at 750°C and higher. Graphite was found to be wet by liquid Na above 150°C and to absorb the Na into its pores above the level of the bulk liquid by capillary action. Experiments with previously irradiated graphite indicated no significant differences in behavior from that of the unirradiated material.

NSA 11:9725

- 1.240 NAA-SR-74 (Del.)  
Epp, A. A. et al. (North American Aviation, Inc., Downey, Calif.)  
Cyclotron Irradiation of Type 347 Stainless Steel Welds in NaK  
at Elevated Temperatures. Jan. 7, 1953. Decl. with deletions April  
11, 1957. Contract AT-11-1-GEN-8. 42 pages.

Capsules of type 347 stainless steel, containing samples of arc welded 347 immersed in NaK of 78 weight-per cent K, were irradiated with deuterons on the 60 inch cyclotron at Berkeley while maintained near 450°C. Power densities ranging from 2500 to 5000 watts/cm<sup>3</sup> were achieved in the weld samples near the NaK interface. The irradiations were between 10 and 20 hours in length, at average beam currents from 1.5 to 3 micro-amperes. Control runs in which the capsules were heated, but not irradiated, and in which a weld sample was irradiated in an evacuated capsule, were also made. No conclusive evidence was obtained that weld corrosion was accelerated in the irradiated runs, compared with unirradiated controls. In addition to weighing the samples, examining them metallographically for evidence of corrosion and analyzing the NaK chemically after the runs, observations were also made of surface hardness, grain size and x-ray-diffraction patterns of the weld samples. No significant differences were found between the irradiated and control samples.

NSA 12:8421

- 1.240 Experimental Breeder Project Report for the Period March 1, 1949  
Through January 31, 1950.  
H. V. Lichtenberger. Mar. 13, 1950. Decl. with deletions Dec. 14,  
1955. 31 p. Contract W-31-109-Eng.-38. (AECD-3925). \$6.30(phOTS);  
\$3.00(mf OTS).

The report covers the status of EBR construction; measurements of Co<sup>60</sup>, Na<sup>24</sup>, and fission-product  $\gamma$ -ray attenuation in concrete; examination of NaK-filled fuel rods and ball check rods for temperature distribution and NaK evaporation; examination of various EBR component mock-ups after operation; heat-transfer characteristics of vertical composite tube (NaK-H<sub>2</sub>O) falling-film-type stream generator and water heater; tests of a rotating liquid seal for a liquid metal pump with a totally enclosed motor; and an experiment on the effects of pile irradiation on a U slug immersed in NaK.

---

### 1.300 DYNAMIC LOOP CORROSION

---

- 1.300 Liquid Metal Investigations, J. W. Semmell, Jr. (GE-FPLD)  
(NASA-AEC Liquid-Metals Corrosion Meeting, Dec. 1961 at BNL)

Na and K in testing up to 1850°F for 1) heat transfer studies, 2) operation of a turbine with K vapor, 3) analysis of liquid metals, 4) development of materials for liquid metal containment, 5) the study of corrosion phenomena. Data included in report. TID-7626 (Part 1)  
(AGN Lib. 2-2786)

1.310 FLOW RATE EFFECTS

- 1.310 CONTINUOUS MASS DIFFUSION IN A NATURAL CONVECTION COLUMN.  
Richard Schwaab Mayer (Univ. of Michigan, Ann Arbor). Univ  
Microfilms (Ann Arbor, Mich.), L. C. Card No. Mic. 58-3709, 145 pp ;  
Dissertation Abstr

CA 53-2702a

- 1.310 WORKING FLUIDS FOR HIGH TEMPERATURE, RANKINE CYCLE, SPACE POWER PLANTS. D. L. Cochran, Aerojet-General Nucleonics, San Ramon, California. Presented at the National Aeronautic and Space Engineering and Manufacturing Meeting (1961)

An analysis is presented of the relative suitability of sodium, potassium, rubidium, and cesium as working fluids in a high temperature, Rankine cycle, space power plant. Turbine inlet temperatures of from 1800 to 2000°F with corresponding condensing temperatures of from 1240 to 1530°F are considered. The criteria by which the fluids are evaluated are the thermodynamic cycle characteristics, heat transfer and fluid friction characteristics, metallurgical compatibility, and the influence of the fluids on the design of the turbine, bearings, radiator, generator, and pump. The turbogenerator unit is thought to be the most critical component and it is found that the working fluid will determine the required number of turbine stages and will therefore establish the turbogenerator bearing arrangement. It is not known whether blade erosion will be a problem. However, since mercury and steam turbines have experienced blade erosion and since potassium has the lowest tendency to cause erosion, potassium appears to be the best over-all working fluid. If blade erosion is found to be of no consequence, then rubidium may result in fewer problems and greater reliability in the turbogenerator unit, and on this basis rubidium would then be the best choice of working fluid.

- 1.310 Corrosion by Liquid Metals  
by Epstein, Leo F.,  
from "Progress in Nuclear Energy, Series 4, Technology and  
Engineering," Vol. 1, Edited by R. Hurst and S. McLain, McGraw-Hill,  
1956. Chapter 6, pp. 366-77. Epstein, Leo F.

There appear to be two basic processes involved in the phenomenon of corrosion by liquid metals (1) chemical reaction and (2) solution. The latter in turn may be divided into two classes (2a) where the rate of attack is determined by the heterogeneous diffusion of solute atoms across the solid-liquid interface ("solution rate limited") and (2b) where the rate of corrosion is fixed by the homogeneous diffusion of the solute through the solvent fluid ("diffusion limited"). Equations for the dependence of these various kinds of corrosion phenomena on temperature, fluid flow velocity, the geometry of the system and similar factors are presented.

---

1.320 DEPOSITION OF SOLUTES

- 1.320 ER-5302  
SUNFLOWER SOLAR RANKINE SYSTEM MERCURY CORROSION AND CORROSION PRODUCT SEPARATOR STATUS SUMMARY (TAPCO) April 16, 1963  
Presented at NASA, Lewis Research Center on the general topic of Mercury Corrosion and Corrosion Product Trapping Experience at TAPCO.

The report has been centered primarily around the effects and test results which have been noted to date on the mercury Rankine cycle systems. Corrosion product separators are discussed and their results analyzed.

- 1.320 NAA-SR-6306  
J. F. Nejedlik, J. J. Owens  
SNAP II POWER CONVERSION SYSTEM - TOPICAL REPORT #14 - MERCURY  
MATERIALS EVALUATION AND SELECTION

Steels, high temperature alloys and refractory metals were screened to evaluate corrosion resistance for long service in a boiling Hg system. High Mn or Ni containing alloys were among the least resistant materials. The Co base Haynes 25 was resistant for a limited time at 900°F after which an increased corrosion rate was observed.

A study of corrosion kinetics which led to excessive sludge deposition was made. The change of temperature coefficient for mass transfer for many of the structural alloys was proposed to indicate a change of mechanism above 700°F. Diffusion controlled corrosion and crevice attack were suggested from the results.

- 1.320 MND-P-2382  
SNAP I POWER CONVERSION SYSTEM MATERIALS DEVELOPMENT  
V. F. Hambor and J. J. Owens  
The Martin Co. Purchase Order OE-0101

Because of the environmental conditions imposed on the SNAP I Power Conversion System, it was necessary to conduct a program to determine the materials to be used in fabricating the system. The very small operating clearances resulting from miniturization of the components made it imperative that formation of any corrosion products be minimized to avoid plugging of small flow passages and interference between parts. In addition, nonmetallic materials had to be evaluated to provide a reliable insulation system for the electrical components and a method for insuring that mercury did not enter the stator windings of the alternator.

Metallic materials were investigated to determine their resistance to corrosive attack by mercury and the effect of mass transfer due to temperature and concentration gradients existing in the system. Materials evaluated included the refractory metals, carbon steels, and the 300 and 400 series stainless steels. As a result of the metallic materials effort, it was concluded that the corrosion contaminants generated produce a more severe problem than the loss of structural material. At 750 to 800°F, most steels were satisfactory, but at 1000°F, the alloys containing Ni were attacked by Hg, but type 446 steel was resistant.

A nonmetallic materials program was conducted to develop suitable insulation and sealing materials for the alternator stator. It was established that the materials and fabrication techniques developed could satisfactorily protect the stator in the SNAP I environment.

- 1.320 "The Contribution of Diffusion to Sludge Formation in Liq Metal-Solid Metal Systems: Sludge Formation in the Hg-Pb System"  
N. J. Hoffman & P. S. Rudman. ASM Trans. Quart 55: 254-9(1962)

Sludge formation is defined as the ejection of solid from the melt. The form of the sludge is of practical importance and ejection modes are 1) Freezing-in on the solid component surface, with resulting surface movement; 2) Nonadherent freezing-in on the solid; 3) Freezing-in on a foreign surface, and 4) pptn of particles within the melts.

CA 56:126211

### 1.330 BOILING AND VAPOR PHASE EFFECTS

- 1.330 Vapor-Liquid Corrosion Studies in Mercury and Sodium Systems  
A. Fleitman, A. Romano, and C. Klamat (BNL) (NASA-AEC Liquid Metal Corrosion Meeting Dec. 1961 at BNL)

Corrosive behavior of liquid Hg and Hg vapor from 600-1400°F, and of liquid Na and Na vapor from 1500-2400°F. Refractory metals including Cb-12r alloy are under investigation in loops and capsules. Wetting and inhibitors tested. TID-7626 (Part 1) (AGN Lib. 2-2786)

SNAP 1 POWER CONVERSION SYSTEM MATERIALS DEVELOPMENT

V. F. Hambor and J. J. Owens

The Martin Co. Purchase Order OE-0101 June 1960

Because of the environmental conditions imposed on the SNAP 1 Power Conversion System, it was necessary to conduct a program to determine the materials to be used in fabricating the system. The very small operating clearances resulting from miniturization of the components made it imperative that formation of any corrosion products be minimized to avoid plugging of small flow passages and interference between parts. In addition, nonmetallic materials had to be evaluated to provide a reliable insulation system for the electrical components and a method for insuring that mercury did not enter the stator windings of the alternator.

Metallic materials were investigated to determine their resistance to corrosive attack by mercury and the effect of mass transfer due to temperature and concentration gradients existing in the system. Materials evaluated included the refractory metals, carbon steels, and the 300 and 400 series stainless steels. As a result of the metallic materials effort, it was concluded that the corrosion contaminants generated produce a more severe problem than the loss of structural material. At 750 to 800°F, most steels were satisfactory, but at 1000°F, the alloys containing Ni were attacked by Hg but type 446 steel was resistant.

A nonmetallic materials program was conducted to develop suitable insulation and sealing materials for the alternator stator. It was established that the materials and fabrication techniques developed could satisfactorily protect the stator in the SNAP 1 environment.

1.330 Liquid and Vapor Alkali-Metal Corrosion (BMI)

E. M. Simons, NASA TN-D-769, 1960

Data for NaK capsule, NaK loop, Na loop, Na purity, Na as a lubricant, K vapor, K liquid and vapor. NSA 15:13279

## 1.330

BML-2446

REACTOR HEAT TRANSFER INFORMATION MEETING HELD AT BROOKHAVEN NATIONAL LABORATORY, OCTOBER 18-19, 1954. Dec. 1955. 195p.

\$1.00(OTS); Dep.; Ind. Dep.; Dep.(mc).

The following unclassified papers, presented at the Reactor Heat Transfer Information Meeting in October, 1954, are included: Heat Transfer Rates to Cross-Flowing Mercury in a Staggered Tube Bank; Specific Heat of Liquid Metal and Salt Mixtures; The Effect of Gas Entrainment on the Heat Transfer Characteristics of Liquid Mercury; Flow in a Thermal Convection Harp in the Grashof Modulus Range From  $10^4$  to  $10^6$ ; Theoretical and Experimental Investigation of Heat Transfer by Laminar Natural Convection Between Parallel Plates; Remarks on Forced Heat Convection in Cylindrical Channels; Potential and Parabolic Velocity Distributions; High Temperature Liquids; Heat Transfer to Boiling Water Forced Through an Electrically Heated Tube; Boiling Density Studies in Multiple Rectangular Channels; Measurement and Prediction of Density Transients in a Volume-Heated Boiling System; Heat Transfer and Corrosion Tests for a Sodium-Cooled Fast Breeder Reactor; and Free Convection in Narrow Vertical Liquid Metal Annuli.

1.330 NYO-3148

BOILING AND CONDENSING OF LIQUID METALS; PROGRESS REPORT. C. F. Bonilla, J. S. Busch, H. T. Chu and B. Misra. Apr. 24, 1952. 12p. Contract AT(30-1)-1042.

Preliminary data have been obtained on the boiling at atmospheric pressure of a shallow layer of Hg on a horizontal iron-plated surface. The boiling film coefficient of heat transfer,  $h$ , ranged from 1600 to 8400 Btu/hr x ft<sup>2</sup> x °F. No film boiling was observed although a heat flow rate of 260,000 Btu/hr x ft<sup>2</sup> was reached. Hg vapor at atmospheric pressure was condensed on a short water-cooled vertical iron tube. Dropwise condensation was obtained, but seemed to impair the heat transfer, if anything, on account of the adherence of the droplets to the surface. Droplets ranged from 1 mm in diameter down to dust, and at intervals a slide would occur of all of the droplets on a given area. The condensing film heat transfer coefficients were very low, ranging from 220 to 530 Btu/hr x ft<sup>2</sup> x °F. They were apparently adversely affected by a mercury oxide film that built up on the surface, and/or by traces of noncondensable gas. More reliable data on the thermoelectric force of the thermocouple Fe-Hg have been obtained, which are approximately 10% higher than the previous results. The millivolts of a couple with its cold junction at 0°C and hot junction at  $t_3$ °C is given, up to about 400°C, by  $E = 0.01939 t_3 - 8.835 \times 10^{-6} t_3^2 - 9.675 \times 10^{-9} t_3^3$ .

---

1.340 CONDENSATION OF VAPOR

1.340 ER-5302

SUNFLOWER SOLAR RANKINE SYSTEM MERCURY CORROSION AND CORROSION PRODUCT SEPARATOR STATUS SUMMARY. (TAPCO) April 16, 1963

Presented at NASA, Lewis Research Center on the general topic of Mercury Corrosion and Corrosion Product Trapping Experience at TAPCO.

The report has been centered primarily around the effects and test results which have been noted to date on the mercury Rankine cycle systems. Corrosion product separators are discussed and their results analyzed.

1.340 VAPOR-LIQUID CORROSION STUDIES IN MERCURY AND SODIUM SYSTEMS

A. Fleitman, A. Romano, and C. Klamat (BNL) (NASA-AEC Liquid Metal Corrosion Meeting Dec. 1961 at BNL)

Corrosive behavior of liquid Hg and Hg vapor from 600-1400°F, and of liquid Na and Na vapor from 1500-2400°F. Refractory metals including Cb-1Zr alloy are under investigation in loops and capsules. Wetting and inhibitors tested. TID-7626 (Part 1) (AGN Lib. 2-2786)

1.340 LIQUID AND VAPOR ALKALI-METAL CORROSION (BMT)

E. M. Simons, NASA TN-D-769, 1960

Data for NaK capsule, NaK loop, Na loop, Na purity, Na as a lubricant, K vapor, K liquid and vapor.

NSA 15:13279

1.340 TID 3544

HEAT TRANSFER IN THE CONDENSATION OF METAL VAPORS: MERCURY AND SODIUM UP TO ATMOSPHERIC PRESSURE. Balabhadra Misra and Charles F. Bonilla.

Chem. Engr. Progr. Symposium Ser. 52, No. 18, 7-21(1956). NSA 12:15603.

1.340

Boiling and Condensing of Liquid Metals

C. F. Bonilla and B. Misra. April 25, 1953. 9p.

Contract AT(30-1)-1042. NYO-3152 Dep.; Ind. Dep.

Additional runs have been made on the condensing of Hg vapor at atmospheric pressure and 330,000 to 650,000 Btu/hr-ft<sup>2</sup> on carbon-steel, stainless steel, and Ni, under wetting, semiwetting, and nonwetting conditions. The highest heat-transfer coefficient observed under any conditions was 2345 Btu/hr-ft<sup>2</sup>-°F, for completely wetted Ni, which is less than 20% of the theoretical Nusselt value. Tests run in the presence of H and of N showed that traces of inert gas were not causing the decrease in coefficient. It is believed that the decrease is due to thermal contact resistance between the Hg and the condensing surface. This hypothesis is supported by earlier work on contact resistance.

1.340

NYO-3150

BOILING AND CONDENSING OF LIQUID METALS. C. F. Bonilla. Oct. 24, 1952. 6p. Dep.; J. Am. Chem. Soc. 74, 2352-3(1952).

Condensation data for Hg vapor on vertical low-C steel and 304 stainless steel tubes have been obtained at pressures from 2.3 to 15 lbs/in.<sup>2</sup>. Drop-wise condensation was always obtained. The film coefficient of heat transfer ranged from 700 to 1800 Btu/hr x ft<sup>2</sup> x °F, much lower than expected. Traces of inert gas may cause this effect, which is being studied further. A horizontal plate apparatus for the boiling of Na has been designed and is under construction.

1.340

NYO-3154

THE CONDENSING OF MERCURY AND SODIUM VAPOR AT ATMOSPHERIC AND LOWER PRESSURES. C. F. Bonilla and B. Misra. Nov. 1, 1954. 59p. Contract AT(30-1)-1042. CU-9-54-AT-1042-Ch.E. Proceedings of Heat Transfer Symposium sponsored by AIChE and ASME, Louisville, Ky., Mar. 20-23, 1955.

Heat-transfer coefficients were determined for Hg vapor condensing on both water and air-cooled vertical carbon steel, Cu-plated steel, Ni, type 304 and stainless steel condensers, 0.5 in. OD and 0.5 to 3 in. in length. Experiments were also carried out on a 4.5 in. long, 0.5 in. OD Ni--stainless steel composite tube condenser, both in horizontal and vertical positions. Visual observations, still photographs, and Fastax moving pictures showed film condensation on Cu-plated steel and Ni surfaces and dropwise condensation on stainless steel surfaces. On steel condensation was usually dropwise near the top and filmwise near the bottom. The heat velocity varied from about 25,000 Btu/hr/ft<sup>2</sup> at 0.5 psia with air cooling to about 750,000 at 15 psia with water cooling, while the heat-transfer coefficients ranged from ~ 3000 to ~ 10,000 Btu/hr/ft<sup>2</sup>/°F for film-type condensation and from about 4000 to over 100,000 for dropwise condensation. For measuring directly the temperature drop through the condensate film or from the vapor to the surface of the condenser, Fe-Hg and Ni-Hg differential thermocouples, as well as the Ni-stainless steel composition condensers themselves, were successfully employed. Condensing-heat-transfer studies for Na vapor were also carried out on a bi-metallic Ni--stainless steel condenser, using the condenser itself as its own thermocouple. The heat velocities varied from about 60,000 Btu/hr/ft<sup>2</sup> at 650°C to about 100,000 at 870°C, giving heat-transfer coefficients ranging from 11,000 to 13,000 Btu/hr/ft<sup>2</sup>/°F. The condensing-heat-transfer coefficients obtained for Hg and Na are only a small fraction of the Nusselt equation values for film-type condensation. 16 figures.



AND SYSTEM IMPURITIES

1.410 ACCELERATED CORROSION DUE TO OXYGEN, NITROGEN,

AND OTHER GASES

- 1.410 Liquid Metal Corr. Mechanisms, J. R. Weeks, C. J. Klamut and D. H. Gurensky (USAEC) IAEA Preprint CN-13/11 53p.

To be published in Proceedings of the IAEA Conference on the Corr. of Reactor Materials held in Salzburg 4-9 June, 1962

The corr. of solid metals by liquid metal coolants & fuels is a complex process. Kinetics of dissolution and pptn of solid metals in liq metal, and complex multicomponent solubilities and their temp coefficients are both part of the corrosion mechanism. In addition, non-metallic impurities (O, N, C) affect both the kinetics and solubilities. NSA 16:22155

- 1.410 Alkali-Metal Corrosion Studies  
E. E. Hoffman, ORNL-3313, Annual Report, May 1962

The physical properties of alkali metals make them highly desirable as nuclear coolants and heat-transfer media. Unfortunately, the hazards associated with any leakage of these fluids as extensive use. In most cases, utilization has been limited to those systems in which no other heat-transfer fluid meets the requirements. For several years this group has been studying various facets of the corrosion problems inherent in containing flowing alkali metals at high temperature. During the past year, investigations were conducted on the optimum techniques for removing nonmetallic impurities and the development of suitable analytical procedures for determining the purity of alkali metals, on the relation between oxygen distribution and corrosion of refractory metals in contact with lithium, and on the use of a nickel-base alloy for containing boiling potassium.

- 1.410 Corrosion Problems in Liquid Metal Cooled Nuclear Reactors. A. Draycott Chemical Processing, v. 13, Apr. 1960, p. 27-35.

Liquid metals are particularly suitable as coolants in fast reactors. Corrosion problems with Na are due mainly to the presence of oxygen in the metal. Stainless steel is suitable for use with liquid Na while Be and Cb require special precautionary measures.

(R6m; SS, Zr, Be, Cb, Bi, Na)

- 1.410 METALLURGICAL INVESTIGATIONS OF SODIUM HEAT TRANSFER RIG,  
Ward, A. G., and Taylor, J. W.  
(Gt. Britain Atomic Energy Research Estab.) Harwell, Berks,  
England) AERE-M/M-148, 18 p. Feb. 1957

A study was made of the attack of stainless steel and Ni by Na, both oxygen-free and contaminated, at temperatures in the range 300 to 600 C in static and dynamic tests. A number of miscellaneous metallurgical investigations on components taken from a stainless steel/Ni double annulus heat exchanger rig are also reported. Under the conditions of test, stainless steel of the 18 wt. % Cr-8 wt. % Ni type containing free carbide, undergoes considerable attack, both in static and dynamic tests in Na normally free from and also heavily contaminated with O<sub>2</sub>. From the evidence available, it is suggested that the mode of attack consists of a decarburizing action which proceeds intergranularly and modifies the spheroidal carbide in the affected region by diffusion of this phase into the matrix. Under similar test conditions Ni undergoes no detectable corrosion even at the highest temperature. It is recommended that prior inspection be carried out on stainless steel for use in systems containing Na at temperatures above 300 C, to ensure that the steel specification has been fulfilled and, that the material is devoid of free carbide. AD 256 511

1.420 ACCELERATED CORROSION DUE TO METALLIC SOLUTES

- 1.420 THE ACCELERATED CORROSION OF METALS  
Third Quarterly Report, Initial Exploratory Studies,  
March 16 - June, 1960.  
David A. Jackson, Jr. (Virginia Institute for Scientific Research,  
Richmond). June 27, 1960. Contract DA 18-108-405-CML-518. 28p.  
(AD-237775)

A survey to find a unifying principle that may be helpful in determining the mechanism of accelerated metal corrosion is reported. Corrosion found in a number of metals, when in contact with metals and alloys that are liquid below 35°C was observed. The types of deterioration noted include an accelerated oxidation rate of aluminum and magnesium in contact with Hg and its alloys and metal cracking such as that observed with aluminum, zinc, and tin in contact with gallium and its alloys.

NSA 15:13264

- 1.420 Siliconizing of Metals in Liquid NaK by Fisher, E. S. et al  
(Argonne National Lab., Lemont, Ill.) U. S. Atomic Energy Commission  
TID-7526, 268-81 (1957).

A description of the method and apparatus used to immerse samples of U in molten NaK without contaminating the surface of the specimen. Si is added to the bath in controlled amounts. Present method produces corrosion, but an excellent means of introducing Si in amounts for preparing single crystals of U.

CA 51:11956

- 1.420     Fundamentals of Liquid Metal Corrosion  
Manly, W. D.  
Corrosion 12, No. 7, 46-52(1956).

The corrosion of structural metals in liquid metal is for the most part a result of solubility of the various constituents of the metal alloy in the liquid metal. The manner in which this solution manifests itself gives rise to many types of attack, ranging from a simple solution type attack to a deep intergranular attack with the preferential leeching of one constituent of an alloy. Examples of the many types of corrosion experienced with solid metal-liquid metal systems are illustrated. The role of impurities on the corrosion is discussed.

In addition to the solution stage, which would soon disappear in a static one metal system on reaching a solubility limit, the corrosion of metals can be continued through the removal of materials from solution in the liquid metal with a temperature gradient or by dissimilar metal transfer. The transfer of metal in a plumbing system by the mechanism of mass transfer-temperature gradient and dissimilar metal transfer will greatly increase the amount of corrosion as compared to the results obtained at static systems. Examples of temperature gradient mass transfer and dissimilar metal transfer are reviewed, and factors governing the occurrence of these phenomenon are outlined.

- 1.420     AERE-X/R-1806  
Cambridge (Univ.), England  
INTERACTIONS BETWEEN SOLID AND LIQUID METALS AND ALLOYS.  
V. W. Eldred. 1953. 242p.

This report was written in the early part of 1953 and was based on work carried out at Cambridge in the preceding three years.

A technique for carrying out long-term corrosion tests is described. It has been applied to the investigation of over forty systems involving pure metals in contact with liquid Bi, Cd, Pb, Hg, K, Na, Sn and Zn at temperatures up to 550°C for periods of contact up to 300 hr. A series of ferrous and non-ferrous alloys has also been investigated under similar conditions in contact with the same liquid discussed. Criteria for the classification of combinations of solid and liquid metals and alloys according to their corrosive behavior are put forward and applied to the systems investigated. The factors controlling the rate of solution of a solid metal in a liquid metal under various conditions are discussed theoretically in the light of the experimental results. The knowledge at present available with regard to metals and alloys manifesting a high corrosion resistance to liquid metals is considered and the characteristics of such systems are discussed. A method of predicting further systems of a similar character is suggested. (auth)

NSA-10-7696

---

1.430     EMBRITTLMENT OF CONTAINMENT MATERIALS

- 1.430     Oxygen-Exchange Thermodynamics in Liquid Metal Corrosion  
J. R. Weeks, Brookhaven National Laboratory, BNL 728 (C-33) 1962.

Oxygen-exchange may promote embrittlement of the container metal by formation of container-metal oxides which may precipitate internally after oxygen diffusion, as Cb, Ta, Zr by Na + O or K + O.

- 1.430     AD282680 RIAS, Inc, Baltimore, Md.    Effects of Surface and Environment on the Mechanical Properties of Materials  
A.R.C. Westwood, M. H. Kamdar    June 62. Final Report  
(WAL TR 832/1-6)

Observations and conclusions are briefly reported on : (1) Effect of adsorbed polar molecules on the mechanisms and dissolution behavior of ionic crystals, (rebinders - effect, etch - tunneling phenomenon, anomalous solution, and etching phenomenon, etc.), (2) The surface sensitive behavior of ionic crystals, and (3) Embrittlement by liquid metals.

1.430

GE 63 FPD66

ALKALI METALS BOILING AND CONDENSING INVESTIGATIONSVOL. II - MATERIALS SUPPORT

J. W. Semmel, Jr., W. R. Young, and W. H. Kearns

Space Power and Propulsion Section, GE Co., Cincinnati 15, Ohio.

Final Report for period January 1, 1961 to June 30, 1962.

Published January 14, 1963.

Materials support was provided for alkali metals boiling and condensing investigations which required the construction of a 300 KW heat transfer loop from L-605 and a 100 KW loop from the Cb-12r alloy. In addition to the preparation of specifications for these materials and assistance in constructing the heat transfer facilities, experimental investigations were conducted to document several aspects of the materials behavior which were pertinent to the loop construction and operation. Experimental work was performed in the following areas: 1) Aging and embrittlement of L-605, 2) Corrosion of L-605 by potassium, and 3) Corrosion and diffusion bonding of Stellite No. 6 and No. 12 hard facing materials in potassium.

AGN Lib. 3-2299

1.430

GA-1508 Maritime Gas-Cooled Reactor Program Reactor MaterialsCompatibility with Impurities in Helium. J. C. Bokos and

H. E. Shoemaker, Gen. Atomic Div. of Gen. Dyn. Jan. 12, 1961, 74 p.

Considers effect of CO also on Nb and its alloys.

NSA: 15-7761

1.430

THE EMBRITTLEMENT OF ALUMINUM-MAGNESIUM ALLOYS BY SODIUM

C. E. Ransley and D. E. J. Talbot (British Aluminum Co., Ltd., Gerrards Cross, Bucks, England). J. Inst. Metals 88, 150-58 (1959) Dec.

The constitutional factors involved in the embrittlement of Al-Mg alloys by Na were investigated, and it is shown that these particular alloys are susceptible to embrittlement because the Na present in them is in the elementary state. As the magnesium content increases, there is a phase change involving a ternary Al-Si-Na compound and dissolved Mg, the net result of which may be represented by the equation:  $(Na Al Si) + Mg = Mg_2 Si + Na$  "free". Solubility determinations on the compounds involved and hydrogen - adsorption measurements under various conditions show that the Na is released when the Mg content exceeds - 2%. The high-temperature properties in both tensile and impact tests are consistent with this result. The mechanism of the embrittlement is discussed in relation to other alloy systems in which trace elements lead to brittle behavior. The embrittlement is ascribed to the adsorption of Na on internal surfaces generated in plastic flow and consequent modification of the growth of grain-boundary cavities.

NSA 14:8767

1.430

Diffusion of Nb and C into Nb and its Carbides. P. V. Gel'd and V. O. Lymbemov. Invest. Akad Nauk. SSSR Otdel Tekh Nauk. Met r Toplwo No. 6 119-26. (In Russian).

$Nb^{95}$  and  $C^{14}$  were used in determining the diffusion of Nb and C in metallic Nb and some of its carbides. The activation energies were determined for Nb diffusion in metal (85 K cal/g-at) and in its carbide  $NbC_{0.98}$  (55 K cal/g - at) as well as for carbon in Nb (32 K cal/g-at) and in  $NbC_{0.98}$ ,  $NbC_{0.75}$  and  $NbC_{0.5}$  ( 32 to 33 K cal/g-at).

NSA: 16-12128

- 1.430 AD 278576 Aero. Material, Naval Air Material Center, Phila.  
EFFECTS OF O<sub>2</sub> IN THE BRITTLE BEHAVIOR OF METALS, E. S. Tankins  
(Rept. No. NAMC-AML(9)-R360FR101)  
Descriptors, brittle materials, liquid metals; metals; Fe alloys;  
Ni alloys; chem. equil.; chem. reactions; chem. impurities; thermo-  
dynamics; O<sub>2</sub>.

- 1.430 EFFECT OF ENVIRONMENT ON THE HIGH TEMPERATURE STRENGTH OF METALS.  
M. R. Achter, Naval Research Laboratory.

At elevated temperature, the strength of metals in vacuum or inert gases may be either higher or lower than that measured in a reactive gas. A mechanism to explain this reversal of the atmosphere effect has been proposed based on two competing processes. Adsorption of gas facilitates crack propagation while oxidation and similar reactions harden and strengthen a metal. The controlling process is determined by temperature and stress. Current studies designed to investigate the operation of these processes are presented.

A series of experiments has been conducted to investigate the effect of gas adsorption on crack propagation in creep and fatigue. Nickel is inert toward nitrogen, yet it is appreciably weaker in this gas than in vacuum. Metallographic studies show that this reduction in strength is related to an increase in number of intergranular cracks when the test is conducted in the gas. Changes in purity of both the metal and the gas affect the results and are indicative of the mechanism of the process. The results are discussed in terms of a model in which gas adsorption at the tip of a crack reduces the work required to break intermetallic bonds.

A sufficiently high temperatures, formation of load bearing oxide layers in grain boundary cracks, it is shown, can be an important source of oxidation strengthening. The measured rupture strength of sintered nickel oxide layers is of the right magnitude to account for some instances of strengthening and for the occurrence of anomalous fillet fractures in nickel creep specimens.

- 1.430 AD 265-808 The Reaction of Certain Oxides and Carbides with Refract. Metals at High Temps. (Translation)

Results are presented of an investigation of the contact reaction of BeO, MgO, ZrO<sub>2</sub> and metal carbides (Zr, Hf, Nb and Ta) with Nb, Mo, and W at temperatures up to 2100°C. Oxides of chemically pure Be and Mg and ZrO<sub>2</sub> stabilized with CaO, ZrC, HfC, NbC and TaC of stoichiometric composition and also industrially pure refractory metals were used. An oxide or carbide was pressed, after heating for 3 to 5 min. on a hot forging press, onto a refractory metal sample. The products obtained were kept in a vacuum furnace with a graphite heater at temps. from 1000 to 1600 to 2100°C for 0.5 to 5 hrs. After extraction, the ends were ground, polished and examined metallographically. Tungsten had the greatest stability with BeO, Mo and with MgO and Mo with stabilized ZrO<sub>2</sub>.

- 1.430 AEC(TR)3321 Investigation of the Diffusion of Boron and Carbon in Certain Metals of Transition Groups. G. V. Lamsonov, EVP Latisheva, 20 p. (1956).

The investigation of diff. of B and C into Ti, Zr, Nb, Ta, Mo and W was performed. On the basis of the X-ray, chem. analysis and also on basis of measurement of microhardness and of the  $\Delta$ wt of specimen, it was established that the diff. of B and C in all the metals indicated is reactive. It is accompanied by formation of the corresponding boride and carbide phases. The values of the activation energies during diffusion agree well with the physical constants of the transition metals and with corresponding borides and carbide phases.

NSA: 12-13148

- 1.430 ARF 2120-4 I.T.T. Armour Res. Found. Niobium Phase Diagrams - Manu. Report on Nb-C System, R. P. Elliott, May 6, 1959.

The Nb-C system has been determined by X-ray and metallog. exam. of sintered and arc cast alloys. 2 carbides exist - hexag. Nb<sub>2</sub>-C with a limited range of homogeneity, and cubic Nb-C with solubility range from 8.25 to 10.25 wt % C. Dilute alloys freeze by eutectic reaction at 2230°C.....

NSA: 13-16195

- 1.430 AEC TR4362 Heats of Format. of Nb Oxides and Carbides.

The heats of combustion of Nb oxides, carbides and hydrides and Nb metal were determined. As a check, the values of graphite and C<sub>2</sub>H<sub>2</sub> were also determined. The heats of formation were then calculated from these data.

NSA: 15-9440

---

## 1.500 INTERGRANULAR ATTACK AND EMBRITTLEMENT

### 1.500 STRESS-CORROSION CRACKING IN LIQUID METALS

W. Rostoker, Armour Research Foundation, BNL 728 1962

From this viewpoint, embrittlement by liquid metals is integrated into existing mechanisms and theories of brittle fracture.

- 1.500 The Embrittlement of Nb in H<sub>2</sub> Contaminated NaK,  
A. Thorley, E. C. Tyzack (Reactor Materials Lab, Culcheth, Eng.)  
Preprint SM 26/49, 34 p. (To be printed in the Proceedings of  
IAEA Symposium on Thermodynamics of Nuclear Materials, held in  
Vienna, 21-25 March 62).

A study was made of uptake and equilibrium levels of H<sub>2</sub> attained by Nb specimens exposed to dynamic NaK (70% K) alloy circulated in an electro-magnetic pumped circuit at 350°C.... The extent of embrittlement of Nb at various H<sub>2</sub> levels was also evaluated by mechanical tests.  
NSA 16:25402

- 1.500 MASS-TRANSPORT AND CORROSION OF IRON-BASED ALLOYS IN LIQUID METALS  
G. W. Horsley (Atomic Energy Research Establishment, Harwell, Berks,  
Eng.). J. Nucl Energy Part B. Reactor Technol. 1. 84-91 (1959) Aug.

The application of mass-transport equations to the corrosion of metals by liquid metals is discussed. Calculated corrosion rates are compared with experimentally determined rates. It is concluded that diffusion controlled solution attack, although significant, may not under conditions of interest to reactor engineers be as serious as either inter-granular attack or chemically assisted mass-transport. The mechanism of intergranular attack, the thermodynamics of an example of chemically assisted mass-transport, the role of oxygen in sodium-stainless steel circuits, and methods of reducing mass-transport of iron are discussed. (auth)

NSA 14-1-587

- 1.500 ORNL 2-422 (Del)  
Metallurgy Division Annual Progress Report for Period Ending  
Oct. 10, 1957. Dec. 13, 1957. Decl. with deletions Oct. 29, 1959.  
147p. Contract W-7405-eng-26. OTS.

Na and NaK pumped Inconel loops. Studies include corrosion,  
mass transfer, H<sub>2</sub> embrittlement, and purification. NSA 14:1763

1.510 BASIC CAUSES

- 1.510 The Effect of Molten Metals on Stressed Solid Metals.  
W. A. Morgan. Murex Ltd. Review, v. 2, no. 22, 1960, p. 62-75.

Summary of the published work on the embrittlement of solid metals by lower melting point liquid metals. Some theories for this type of failure. 57 ref. (Q26s, 3-66, 2-66) (Hg: brazing alloys and solder)

- 1.510 EMBRITTLMENT BY LIQUID METALS  
W. Rostoker, J. M. McCaughey, and H. Markus  
New York, Reinhold Publishing Corp. 1960, 169 p.

Published data on embrittlement by liquid metals are collected, reviewed, and evaluated. In addition, unpublished results of the latest research in this field are given. The seven chapters cover literature reviews, occurrence of liquid metal embrittlement, crack propagation, factors influencing embrittlement, delayed failure, theory of metal fracture, and mechanisms of liquid metal embrittlement, respectively.

NSA 15:1802

- 1.510 EMBRITTLMENT OF SOLID METALS IN A LIQUID METAL  
W. A. Morgan  
(Dept. of Mines and Technical Surveys, Ottawa) Metal Treatment and Drop Forging 26, 333-9, (1959) Sept.

A review is given of the published work on the embrittlement of solid metals by lower melting-point liquid metals. Included in the discussion are some of the theories for intergranular failure resulting from soldering and brazing operations on stressed materials. (57 references)

NSA 14:18202

- 1.510 CA57:148501  
"The Possible Mechanism for the Destruction of Stressed Metals Under the Influence of Liquid Metals," G. V. Karpenks, Tr. Seminara po Zharostockim Materialam, Akad. Nuch. Ukr. SSR Inst. Metallokeram. i Spets. Splavov, 1959 No. 4 79-85 (Pub. 1959).

A detailed literature survey is given. The most likely mechanisms seems to be the corrosive effect of liquid metals and the diffusion of liquid metals into the stressed metal lattice.

- 1.510 AD 255-358, Failure of Metals in Contact with Liquid Metals,  
Translation by WADD.

No abstract but contains: "Descriptions" Liquid metals, metals, failure, machines, stresses aluminum, mercury.

- 1.510 NP-6646 UNCLASSIFIED  
Cambridge Univ., England  
The Effect of Stress on the Interactions Between Solid and Liquid Metals and Alloys. Interim Progress Report No. 2.  
Morgan, W. A.  
May 1951. 12p. Contract 13/5/165/226. (AERE-S/Pr-2087(May 1951)).

A series of experiments is presented for determining effects of molten metal penetration on the room-temperature mechanical properties of the pure metal. A similar series of experiments as above will be carried out, but the solid metal specimens will be stressed to varying extents during the heating in contact with the molten metal. Tensile testing to fracture of specimens at various temperatures and rates of loading while in the pure molten metal environment is reported. Fatigue testing is also reported. (W.L.H.)

INTERGRANULAR ATTACK

- 1.520 The Effect of Molten Metals on Stressed Solid Metals.  
W. A. Morgan. Murex Ltd. Review, v. 2, no. 22, 1960, p. 62-75.

Summary of the published work on the embrittlement of solid metals by lower melting point liquid metals. Some theories for this type of failure. 57 ref. (Q26s, 3-66, 2-66) (Hg: brazing alloys and solder)

- 1.520 AERE-M/M-148  
Gt. Brit. Atomic Energy Research Establishment, Harwell, Berks, England.  
Metallurgical Investigations of Sodium Heat Transfer RIG. 18p. by  
Ward, A. G. and J. W. Taylor. Feb. 1957.

A study was made of the attack of stainless steel and Ni by Na, both oxygen free and contaminated, at temperatures in the range 300 to 600°C in static and dynamic tests. A number of miscellaneous metallurgical investigations on components taken from a stainless steel/Ni double annulus heat exchange rig are also reported. Under the conditions of test, stainless steel of the 18 wt. % Cr-8 Wt. % Ni type containing free carbide, undergoes considerable attack, both in static and dynamic tests in Na nominally free from and also heavily contaminated with O<sub>2</sub>. From the evidence available it is suggested that the mode of attack consists of a decarburizing action which proceeds intergranularly and modifies the spheroidal carbide in the affected region by diffusion of this phase into the matrix. Under similar test conditions Ni undergoes no detectable corrosion even at the highest temperature. It is recommended that prior inspection be carried out on stainless steel for use in systems containing Na at temperatures above 300°C, to ensure that the steel specification has been fulfilled and, that the material is devoid of free carbide.

NSA 11:9285

- 1.520 PRELIMINARY STUDY OF THE FATIGUE OF METALS IN LIQUID METAL ENVIRONMENTS  
J. W. Martin and G. C. Smith. Metallurgia 54, 227-32, 238(1956).

A series of expts. with 70/30 brass showed that amalgamation reduced the life at all stresses. The effect appears to be a min. in the region of the fatigue limit and increases rapidly as the stress amplitude is increased. In the amalgamated specimens, intergranular failure occurred over the whole of the fracture surface, although the zone wetted by Hg did not extend to the center of the fracture. In the case of 60/40 brass, specimens were fractured with and without Hg. In the fracture of an amalgamated specimen the path of the cracks tends to follow the  $\beta$ -matrix rather than run through the  $\alpha$ -phase, but in the nonamalgamated specimen the path of the fracture is random. The lower the fatigue stresses, the greater the depth of penetration of the Hg. Tests were run with mild steel in contact with liquid Sn and 18/8 stainless in contact with liquid Na. In the case of the mild steel, the fatigue limit is raised at elevated temperature and life is increased at stresses above the fatigue limit. In contact with liquid Sn, the fatigue limit is lowered and life at stresses above the fatigue limit is reduced. The proportional decrease in life is greatest at the higher stresses employed and least in the region of the fatigue limit. In the case of 18/8 stainless steel in contact with liquid Na, life does not seem significantly different from empty specimens, although a number of cracks have been observed in specimens containing Na. 11 references.

CA 51-998a



- 1.620 NAA SR6801, Analysis of Results of a Na Cold Trap Experiment, July 30, 62.

Report describes two processes: (1) Batch or simple crystallization and (2) Circulation cold trapping employing an economizer and oxide storage bin positioned within the tank. System 1 worked satisfactorily; System 2 design (as designed) did not work.

NSA 16:28538

- 1.620 Alkali-Metal Purification

A. P. Litman, ORNL-3313, Annual Report, May 1962

Impurities, such as oxygen, nitrogen, and carbon, in alkali metals may cause alteration of the properties of container materials, affect mass transfer, or cause plugging due to precipitation of alkali-metal impurity compounds. Studies of methods for purifying the alkali metals have included low-temperature filtration, cold trapping, vacuum distillation, and gettering with active metals. Recent investigations by this group point to gettering, combined with low-temperature filtration in some cases, as the most practical and efficient method for lowering the oxygen content of the alkali metals. The gettering technique relies on the relative thermodynamic activity of the oxygen in the alkali metal vs that of the solid metal. The coefficient and the system kinetics are important factors in the purification process.

For purification, solubility, and corrosion studies, accurate analytical procedures are needed for several impurities. The lack of such procedures, especially for oxygen in the alkali metals, has seriously hampered progress in the areas of investigation mentioned above. For example, the correlation between the methods used in determining oxygen in potassium was poor, and when controlled oxygen additions were made, all the oxygen was not extracted from the potassium samples. A comprehensive review of existing analytical methods verifies the need for better techniques. An improvement may result from forthcoming modifications to the analytical equipment, revision of present sampling procedures, and advanced studies on a gettering vacuum-fusion method investigated a few years ago.

---

1.630 INHIBITORS

- 1.630 SOME OBSERVATIONS ON THE INHIBITION OF MERCURY ATTACK ON TITANIUM AND ITS ALLOYS.

James Y. N. Wang, Argonne National Laboratory, 12th Annual AEC Corrosion Symposium, May 20-22, 1963, Castlewood, Pleasanton, Calif.

Nitrided surfaces of titanium and its alloys have been found to be unaffected by liquid mercury at 538°C. At this temperature, mercury vapor attacks certain alloys while others are immune. For instance: the corrosion of a nitrided Ti-8 Mn alloy was found to be insignificant; however, severe corrosion occurs at the nitrided layer of a Ti-7 Al-12 Zr alloy. This corrosion behavior leads one to believe in the probable importance of the chemical and structural nature of these layers.

A study of the effect of metallic additives to mercury on the corrosion resistance of titanium at 538°C has also been made. It is shown that a saturated mercury solution of zirconium or nickel exerts a strong influence in reducing the corrosion effect. The corrosion products formed an adherent protective film which appeared to be consistent with Ti-Zr-Hg or Ti-Ni-Hg compound. These films are thermodynamically stable in the testing environment and may act as a diffusion barrier between solid and liquid.

New titanium alloys and loop test data are presented.

- 1.630 Vapor-Liquid Corrosion Studies in Mercury and Sodium Systems  
A. Fleitman, A. Romano, and C. Klamat (BNL) (NASA-AEC Liquid  
Metal Corrosion Meeting Dec. 1961 at BNL)

Corrosive behavior of liquid Hg and Hg vapor from 600-1400°F,  
and of liquid Na and Na vapor from 1500-2400°F. Refractory metals including  
Cb-12r alloy are under investigation in loops and capsules. Wetting and  
inhibitors tested. TID-7626 (Part 1) (AGN Lib. 2-2786)

- 1.630 IMPROVEMENTS IN OR RELATING TO CORROSION INHIBITION OF FERROUS  
METALS

G. W. Horsley, B. R. T. Frost, and J. T. Maskrey (to United  
Kingdom Atomic Energy Authority) British Patent 878,183.  
Sept. 27, 1961.

A method is described for inhibiting corrosion of the surface of  
a ferrous metal plate having a first surface in contact with a molten metal,  
such as bismuth. The method consists of adding a nitride former (Zirconium  
or titanium) to the molten metal to form a nitride layer on the first surface  
and continuously forming a nitride layer on the second surface of the plate.  
The metal plate is maintained at 500 to 600°C and ammonia is continuously  
fed to the second surface. (N.W.R.)

NSA 15:31137

- 1.630 ER-4103  
THE SNAP II POWER CONVERSION SYSTEM TOPICAL REPORT No. 7  
MERCURY MATERIALS EVALUATION AND SELECTION

(TID-11,307)

J. J. Owens et al., October, 1960. 143p. Thompson-Ramo-  
Wooldridge, Inc., Cleveland, Ohio.

This report presents the results of a two-year material compati-  
bility study and discusses the corrosion mechanisms involved in a system  
in which mercury is the working fluid. Includes 35 references and 11  
bibliographies. (AGN Lib 2-5632)

NSA 15:21096

- 1.630 SOME PROPERTIES OF THIN OXIDE FILMS ON SODIUM-POTASSIUM ALLOY SURFACES  
D. Sutherland and A. W. Smith (United Kingdom Atomic Energy Authority.  
Development and Engineering Group. Dounreay, Caithness, Scotland)  
May 1960 (DEG-MEMO-826)

The reaction of oxygen at low concentrations in nitrogen with NaK  
was investigated. It was found that a thin, almost insoluble, oxide coating  
forms on the alloy. The coating inhibits the absorption of oxygen at con-  
centrations of 1 to 300 ppm.

NSA 15:12901

- 1.630 High-Temperature Corrosion by Coolants (BNL)  
D. H. Gurninsky and C. J. Klamut, NASA TN D-769, 1960

Na and Hg corrosion, Zr inhibitors, solubility studies, and a  
variety of capsule and loop tests.

NSA 15:13270

- 1.630 Liquid-Metal Boiling Systems (MSA), J. W. Mausteller, NASA TN-D-769,  
1960.

K still shows thermal fatigue with massive nitriding in the vapor  
phase - vaporization of Na in a NaK loop - cover gas investigations - NaK  
loops to test among other things the inhibition of mass transport -  
purity of NaK and K - concept of operation with leaks. NSA 15:13284

- 1.630 Liquid Metal Fuel Reactor Experiment. Zirconium Nitride Film Theory Babcock and Wilcox Co. Atomic Energy Division, Lynchburg, Va. B&W-1087, February 1960, 33p. Contract AT(30-1)-1940

According to theory, the corrosion of certain steel alloys is inhibited by the formation of a protective film of ZrN, the nitrogen being present in the steel in the form of nitrides or in solid solution with the metal. The primary purpose of this investigation is to verify existing theory as applied to Croloy 2-1/4 by determining the level of nitrogen present in typical commercial heats, the effects of aluminum and of heat treatment on the nitrogen available for film formation, the minimum nitrogen necessary for film formation, and the effects of C, Mn, Si, N. and residual elements on film formation and retention. Samples from 21 commercial heats of Croloy 2-1/4 were analyzed to determine their nitrogen and aluminum contents. The concentration of nitrogen ran from 0.010 to 0.016%; aluminum, 0.008 to 0.037%. Other specimens from three representative heats were further tested by quenching from 1800 F and then reheating for 24 hr at temperatures from 750 to 1350 F. Analyses indicate that the metal loses a significant portion of its free nitrogen in the 1150 to 1350 F temperature range. A number of vacuum-melted alloys were prepared from ultra-pure materials for corrosion tests to determine the individual effects of minor alloying and residual elements. Owing to the termination of the project, only melting techniques, specimen preparation, and preliminary corrosion tests were completed.

NSA 15:4245

- 1.630 CA55-19543g  
USP 2943034 June 28, 1960 to MSA, J. W. Mausteller.

The inhibitors decrease or prevent the mass transfer of radioactive constituents having a half life longer than  $\text{Na}^{24}$ . Metals such as Ba, Sr, Ca, Ti, Sb, and Mg when used in amounts of approximately 1% by wt in a liquid Na heat transfer system using st steel or other alloy piping inhibit the mass transfer of the radioactive structural materials. Experiments are described showing that the order of effectiveness was the same as the order of listing above.

- 1.630 TID 3544  
ZIRCONIUM AND TITANIUM INHIBIT CORROSION AND MASS TRANSFER OF STEELS BY LIQUID HEAVY METALS. O. F. Kammerer, et. al. Trans. Met. Soc. AIME 212, No. 1, 20-5(1958) Feb. NSA 12:6597

- 1.630 ZIRCONIUM AND TITANIUM INHIBIT CORROSION AND MASS TRANSFER OF STEELS BY LIQUID HEAVY METALS  
O. F. Kammerer, J. R. Weeks, J. Sodofsky, W. E. Miller, and D. H. Gurinsky (Brookhaven Natl. Lab., Upton, N. Y.).  
Trans. Met. Soc. AIME 212, No. 1, 20-5(1958).

Zr and Ti inhibit soln. mass transfer of steels by liquid Bi, Hg, and Pb. It is shown that in Bi and Hg, these adsorb on the surface of the steels and subsequently react with N and possibly C from the steels to form inert, adherent surface layers of ZrN, TiN, or TiN + TiC. Data are presented which describe the condition under which these deposits form. These inhibitors decrease the soln. rate of Fe into Bi, and require a higher supersatn. for pptn. of Fe from Bi. NSA 12:6597

C. L. Mantell  
CA52-7091e

- 1.630 INHIBITION OF CORROSION. J. E. Atherton, Jr., and D. H. Gurinsky  
U. S. Pat. 2,840,467. June 24, 1958. NSA 12:14437

- 1.630 AERE-M/TN-35  
Gt. Brit. Atomic Energy Research Establishment, Harwell, Berks,  
England. INHIBITION OF LIQUID-METAL CORROSION.  
J. W. Taylor. Feb. 10, 1956, 9p. (MSWP-N/18).

From a consideration of the common mechanisms of liquid metal corrosion, additions to liquid metals which inhibit corrosion are classified as scavenging or diffusion-barrier types. Desirable characteristics of both classes of inhibitor are discussed and possible limitations to the zirconium nitride inhibitor, proposed for liquid metal fueled systems based on bismuth, are considered. Suggestions are made for overcoming such limitations and it is recommended that surface layers of the metals molybdenum, tantalum, niobium and possibly beryllium be tested as alternative inhibitors of the diffusion-barrier type. (auth)

NSA-10-6657

- 1.630 NP - 5601  
Progress Report No. 27 for February and March 1955. J. W. Mausteller,  
ed. Apr. 22, 1955. 62p. Contract NObs-65426.

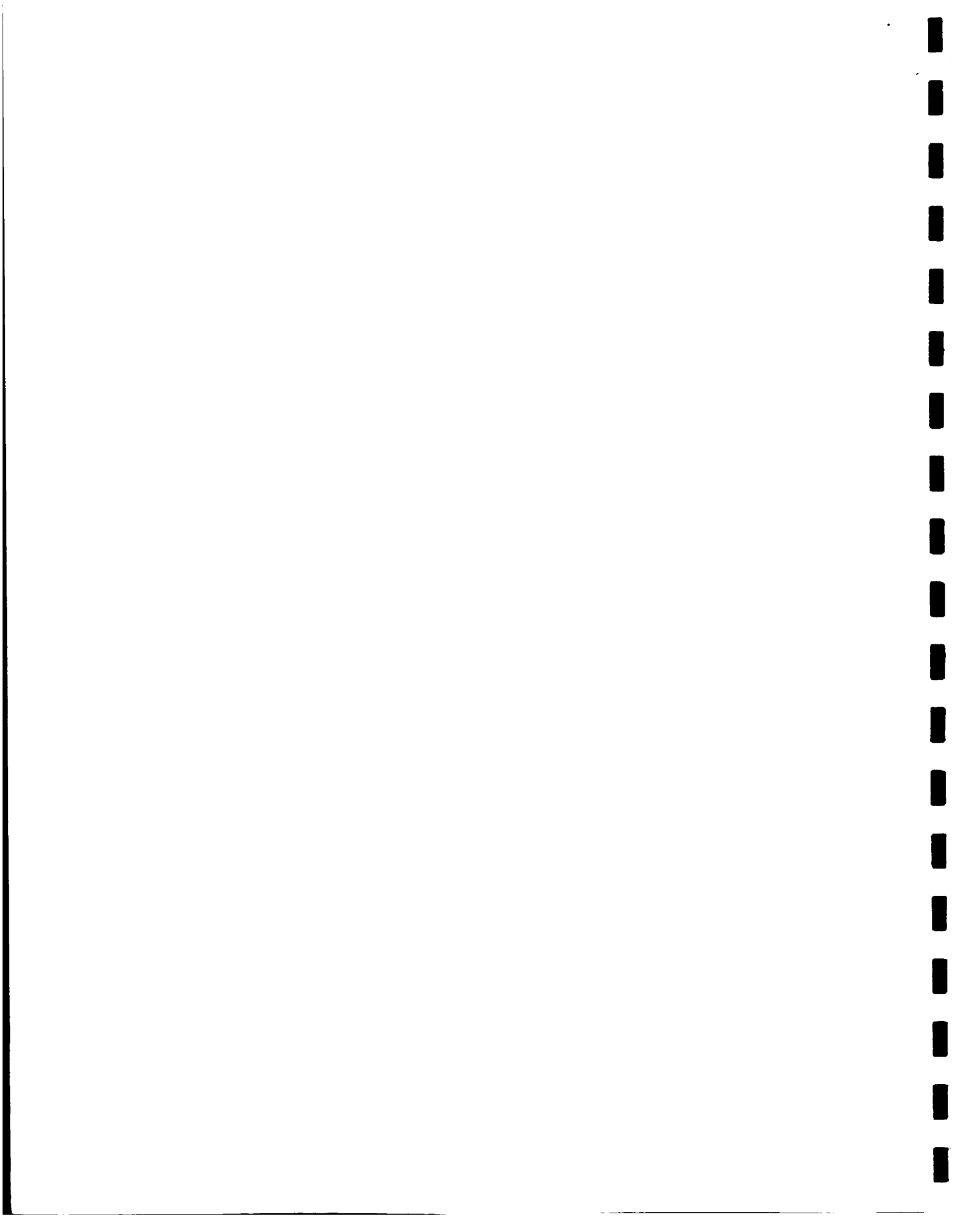
Tests on the Mark B 3000-Kw steam generator are described, including a circulating cold trap and plugging indicator, system cleaning, pump performance, NaK furnace tube failure, boiler water analysis, and heat transfer. Engineering studies are summarized on vent and drain line closures, NaK cross flow exchanger, development of EM pumps, pressure gages, wetting with alkali liquid metals, thermal shock, bellows testing, valve cleaning and testing, and thermal insulation tests in liquid Na. The depression of Na<sub>2</sub>O solubility in Na by K is discussed. Further studies on inhibition of mass transfer of radioactive stainless steel constituents in Na are described. The removal of residual radioactive Na with Na flushes was studied. Further results on radioactive leak contamination and the reactions of molten Zr in water are reported.

- 1.630 ANL-5260 (Del. 2)  
REACTOR ENGINEERING DIVISION QUARTERLY REPORT (FOR) DECEMBER 1,  
1953 THROUGH MARCH 30, 1954. Apr. 15, 1954. Decl. with deletions  
Apr. 8, 1957. 185p.

Boiling Experimental Reactor (BER). An H<sub>2</sub>O-type reactor has been selected for an initial pilot boiling reactor. Information given here pertains to the D<sub>2</sub>O design developed during the course of study. Plate-type and co-extruded tubular fuel element assemblies were considered for this reactor. Several cross section drawings of the proposed design are given. EBR-II. Several tank designs are proposed whereby the primary system, submerged in a Na-filled, double-walled tank, may be connected to the reactor vessel. Moderator, Reflector and Structural Materials. Zn(C<sub>2</sub>H<sub>3</sub>O<sub>2</sub>)<sub>2</sub> and ZnO were found to be effective corrosion inhibitors of 347 stainless steel and 2-S Al. An apparatus was constructed for thermal conductivity determinations of reactor materials up to 1000°F. The embrittling effects of irradiation, H<sub>2</sub>, and temperature on the impact properties of materials were studied. The specimens tested included a variety of stainless steels, Ni-A, Ni alloys, Co alloys, and Zr.

1.640      DESIGN PARAMETERS

To be expanded in the supplement.



2.000

CONTAINMENT MATERIALS FOR LIQUID

METAL SYSTEMS

## 2.100 SUMMARY OF PHYSICAL AND MECHANICAL PROPERTIES

### OF LOOP MATERIALS

- 2.100 ARDC-TR-59-66  
AIR WEAPONS MATERIALS APPLICATIONS HANDBOOK - METALS AND ALLOYS  
First Ed. December 1959, Syracuse Univ. Research Inst.  
ARDC. U.S. Air Force

A compilation of engineering, physical, and mechanical properties of commercially available structural alloys. The data presented includes minimum values of mechanical properties which are acceptable for design purposes, as well as specifying some for various wrought forms and heat treatment conditions. The coverage light weight alloys (Al, Mg, Ti) as well as the high temperature alloys is good. The low alloy steels and industrial types of alloy and carbon steels are not covered.

- 2.100 AD-265 511  
INVESTIGATION OF DUPLEX TUBES  
Stewart, E. Y.  
(Knolls Atomic Power Lab. Schenectady, N. Y) KAPL-1844, 30 p  
(Aug. 1957 Decl. Apr. 9, 1958)

When the two-tube (duplex) test steam generator was retubed only limited information pertaining to the heat transfer characteristics of duplex tubes was available and the fabrication procedures in their manufacture to obtain maximum heat transfer had not been fully developed. Since a 1/11 scale model and three prototype steam generators were to be built with duplex tubes for the SIG/S2G Program an investigational program was initiated to provide this information as quickly as possible. The investigation consisted of a review of the state of the art through a literature survey, a detailed analysis of the transfer of heat through duplex tubes, application of the information obtained to the production of duplex tubes for tests, and a backup duplex tube program. As a result of the investigation, a general fabrication procedure for producing efficient duplex tubes in steam generators heated by liquid metal was recommended.

- 2.100 AD 278354 NOTS China Lake. Metallurgical Prop. of some Explosively Welded Metals. G. A. Hayes, J. Pearson, June 62 (NAVWEPS Rept. No. 7925)

Studies of the explosive welding of Al, brass, Cu, steel, and Ta in various combinations of single & multiple welds are described. Work hardening data and a microstructural analysis indicating the metallurgical properties for explosive welds of similar and dissimilar metal combinations are presented.

- 2.100 AD 281740 Welding of Nonferrous Alloys, Rare Metals and Plastics (Selected Parts) by Foreign Tech Div of AF System Command, WPAFB

- 2.100 NAA-SR-1300  
A SODIUM-GRAPHITE REACTOR STEAM-ELECTRIC STATION FOR 75 MEGAWATTS NET GENERATION. Edward F. Weisner and Warren M. Sybert. Mar. 22, 1955. Decl. Feb. 28, 1957. 65p.

The major design features, nuclear characteristics and performance data for a nuclear fueled central station power plant of 75,000 kw net capacity are presented. The heat source is a Na cooled graphite moderated reactor.



- 2.100 NSA 16:15901  
(FXM-2210) Materials Survey For PWAR-6 Design, L. M. Raring (P&WA Div.  
UAC, Middletown, Conn.) October 17, 1956.

Properties data for PWAR-6 reactor materials are listed. Data are included for Inconel, salt, Na, NaK, thermal insulation, alkylbenzene and Pb.

- 2.100 GEAP-0500  
General Electric Co. Atomic Products Div., Schenectady, N. Y.  
INVESTIGATION OF STAINLESS STEEL-CARBON STEEL COMPOSITE TUBES.  
C. H. Saums and C. H. Kreischer. May 1955, 39p.

A preliminary investigation was made to determine the feasibility of using extruded composite tubing in heat exchanger design. Tests were run to determine the reliability of the bond between the metals and to find the linear coefficient of thermal expansion. It was also desired to establish a reasonable method of welding relatively thin-walled tubes into a heavy tube sheet. Results indicate that extruded composite tubing has a good bond. The linear coefficient of thermal expansion of the sample tested was  $7.31 \times 10^{-6}$  in. in-degrees F. Analysis shows this coefficient to be a function of the ratio of the thicknesses of the two metals. Metallurgically sound welds were produced between the subject tubes and tube sheets of both Type 347 stainless steel and AISI 1035 carbon steel. The most promising results were obtained with stainless steel by using the tungsten inert arc welding process with a trepanned weld preparation. No filler was used on the first weld pass. (auth)

NSA-10-2717

- 2.100 KAPL-M-EEB-7  
Knolls Atomic Power Lab., Schenectady, N. Y.  
The Thermal Expansion and Elevated Temperature Mechanical Strength of Hafnium.  
Report No. 1 on Investigation of Mechanical Properties of Materials  
Sub-Project No. 7. Baldwin, E. E., January 4, 1954. 13p.  
Contract W-31-109-Eng-52

Dimensional stability, thermal expansion up to 1800°F, short time tensile at 1500°F, and stress-rupture in Na at 1200°F tests were made of arc-melted and extruded Hf. It was found that the short-time tensile strength was similar to that of Type 347 stainless steel but the 1200°F rupture strength and coefficient of linear expansion were about one-third those of Type 347 stainless steel.

NSA 10:10846

---

## 2.110 FERRITIC AND MARTENSITIC STEELS

- 2.110 ARDC-TR-59-66  
AIR WEAPONS MATERIALS APPLICATIONS HANDBOOK - METALS AND ALLOYS  
First Ed. December 1959, Syracuse Univ. Research Inst.  
ARDC. U. S. Air Force

A compilation of engineering, physical, and mechanical properties of commercially available structural alloys. The data presented includes minimum values of mechanical properties which are acceptable for design purposes, as well as specifying some for various wrought forms and heat treatment conditions. The coverage light weight alloys (Al, Mg, Ti) as well as the high temperature alloys is good. The low alloy steels and industrial types of alloy and carbon steels are not covered.

- 2.110 Physical Properties of 9Cr-1Mo Ferritic Steels, Technical  
Bulletin 9C - "B&W Croloys" The Babcock and Wilcox Company,  
785 Market Street, San Francisco 3, Calif.

- 2.110 DMIC-42R (also OTS-PB-161192R) 5/24/61  
STANDARD DESIGNATION OF ALLOYS FOR AIRCRAFT AND MISSILES (REVISED)

A source list of government specification numbers and chemical compositions showing trade names and producer of high strength steels, austenitic, martensitic and precipitation hardened steels for low and high temperature applications. Also includes hot work die steels as well as nickel and cobalt base alloys.

- 2.110 SEAMLESS STEEL TUBING - HIGH TEMPERATURE-HIGH PRESSURE SERVICE  
Babcock and Wilcox, Tubular Products Division  
Beaver Falls, Penn. Tech. Bulletin -6H (1959)

Physical and mechanical property data for short time and long time service at elevated temperatures. Effects of environment and metallurgical stability factors are described. Alloys include ferritic alloys with Croloy 9M (9Cr-1Mo) and austenitic steels such as types 304 and 316 stainless steel and other grades. Extensive long time creep and stress-rupture data is presented.

The effect of high temperature oxidizing and reducing environments is discussed. The Croloy 9M (9Cr-1Mo steel) is superior to other ferritic steels in its resistance to decarburizing atmospheres and resistant to hydrogen embrittlement. (Such metallurgical stability factors are highly desirable in liquid metal service.) A bibliography (41 references) on the effects of hydrogen and adverse environmental conditions on steels is presented.

- 2.110 SEAMLESS FERRITIC ALLOY STEEL PIPE FOR HIGH TEMPERATURE SERVICE  
ASTM Specification A-335  
Grade P-17, steel: 9Cr, 1Mo, 0.15 carbon (maximum)

Standard specifications for chemical analysis, dimensional tolerances and quality of ferritic pipe for high temperature service.

- 2.110 PIPE AND TUBES FOR ELEVATED TEMPERATURE SERVICE  
National Tube Division, U. S. Steel - Bulletin #26 (1956)

Technical data including design strengths, ductility, creep rupture and physical properties of steels for high temperature and long life service 9Cr-1Mo steel and other common stainless steels are included.

## 2.120 AUSTENITIC STEELS AND HIGH TEMPERATURE ALLOYS

- 2.120 EFFECT OF ENVIRONMENT ON THE MECHANICAL PROPERTIES OF METALS  
McCoy, H. E., Martin, W. R., and Weir, J. R.  
"Proceedings of the Institute of Environmental Sciences National Meeting, April 5, 6, 7, 1961, Wash. D. C." p. 163-76

The influence of service environment on the mechanical properties of metals is shown to be of practical significance. The relative importance of factors such as chemical reactivity of the material with service environment, effect of environment on surface and grain-boundary energies, temperature, and the ratio of surface area-to-volume is discussed. Methods for carrying out mechanical property tests in simulated service environments at elevated temperatures are illustrated. The effects of an air environment on the creep and stress-rupture properties of type 304 stainless steel and Inconel over the temperature range of 1300 to 1700°F are presented. Investigation of the effects of the component gases, oxygen, and nitrogen, shows that the strengthening effect found in type 304 stainless steel tested in air is associated primarily with an increase in the nitrogen content. The increase in the stress-rupture life of Inconel tested in air is due primarily to the retarding effect which air has on the onset of third-stage creep.

NSA 15:17361

- 2.120 DMIC-42R (also OTS-PB-161192R) 5/24/61  
STANDARD DESIGNATION OF ALLOYS FOR AIRCRAFT AND MISSILES (REVISED)

A source list of government specification numbers and chemical compositions showing trade names and producer of high strength steels, austenitic, martensitic and precipitation hardened steels for low and high temperature applications. Also includes hot work die steels as well as nickel and cobalt base alloys.

- 2.120 ARDC-TR-59-66  
AIR WEAPONS MATERIALS APPLICATIONS HANDBOOK - METALS AND ALLOYS  
First Ed. December 1959, Syracuse Univ. Research Inst.  
ARDC. U. S. Air Force

A compilation of engineering, physical, and mechanical properties of commercially available structural alloys. The data presented includes minimum values of mechanical properties which are acceptable for design purposes, as well as specifying some for various wrought forms and heat treatment conditions. The coverage light weight alloys (Al, Mg, Ti) as well as the high temperature alloys is good. The low alloy steels and industrial types of alloy and carbon steels are not covered.

- 2.120 SEAMLESS STEEL TUBING - HIGH TEMPERATURE - HIGH PRESSURE SERVICE  
Babcock and Wilcox, Tubular Products Division  
Beaver Falls, Penn. Tech. Bulletin-6H (1959)

Physical and mechanical property data for short time and long time service at elevated temperatures. Effects of environment and metallurgical stability factors are described. Alloys include ferritic alloys with Croloy 9M (9Cr-1Mo) and austenitic steels such as Types 304 and 316 stainless steel and other grades. Extensive long time creep and stress-rupture data is presented.

The effect of high temperature oxidizing and reducing environments is discussed. The Croloy 9M (9Cr-1Mo steel) is superior to other ferritic steels in its resistance to decarburizing atmospheres and resistant to hydrogen embrittlement. (Such metallurgical stability factors are highly desirable in liquid metal service.) A bibliography (41 references) on the effects of hydrogen and adverse environmental conditions on steels is presented.

- 2.120 PIPE AND TUBES FOR ELEVATED TEMPERATURE SERVICE  
National Tube Division, U. S. Steel - Bulletin #26 (1956)

Technical data including design strengths, ductility, creep rupture and physical properties of steels for high temperature and long life service 9Cr-1Mo steel and other common stainless steels are included.

- 2.120 AD 265511  
THERMAL-SHOCK TESTING OF HIGH-TEMPERATURE METALLIC MATERIALS  
Hunter, T. A.  
Am. Soc. Testing Materials Spec. Tech. Publ. No. 174, 164-82 (1956)

Thermal shock damage was analyzed theoretically. It is indicated that the scope of the problem is so wide that purely analytical methods must be supplemented by experimental data. In the usual metallic materials intended for high-temperature service, thermal-shock cracking is produced by thermal fatigue except for shapes of greatly varying cross section. Thermal fatigue is a cumulative process which continues until a crack is initiated. Then the failure process becomes a combination of fatigue effects and stress-concentration effects. Large variations of thermal-shock resistance occur within a given material, and for reliable results a sample group of statistical size must be used. Increasing the temperature lowers the thermal-shock resistance of the materials tested. Mechanical fatiguing of Type-347 stainless prior to thermal-shock testing resulted in a decrease in the sensitivity of this material to variations in edge width and a decrease in the width of the scatter band of the data. Thermal heating and cooling without thermal shock has a negligible effect on the thermal-shock resistance of S-816 (wrought) at 1700°F. Coolant tests on Inconel at 2000°F showed little difference in thermal-shock resistance between He and air coolant.

## 2.130 NICKEL AND COBALT BASE ALLOYS

### 2.130 EFFECT OF ENVIRONMENT ON THE MECHANICAL PROPERTIES OF METALS

McCoy, H. E., Martin, W. R., and Weir, J. R.

"Proceedings of the Institute of Environmental Sciences National Meeting, April 5, 6, 7, 1961, Wash. D. C." p. 163-76

The influence of service environment on the mechanical properties of metals is shown to be of practical significance. The relative importance of factors such as chemical reactivity of the material with service environment, effect of environment on surface and grain-boundary energies, temperature, and the ratio of surface area-to-volume is discussed. Methods for carrying out mechanical property tests in simulated service environments at elevated temperatures are illustrated. The effects of an air environment on the creep and stress-rupture properties of type 304 stainless steel and Inconel over the temperature range of 1300 to 1700°F are presented. Investigation of the effects of the component gases, oxygen, and nitrogen, shows that the strengthening effect found in type 304 stainless steel tested in air is associated primarily with an increase in the nitrogen content. The increase in the stress-rupture life of Inconel tested in air is due primarily to the retarding effect which air has on the onset of third-stage creep.

NSA 15:17361

### 2.130 HIGH-FREQUENCY SURFACE THERMAL FATIGUE CYCLING OF INCONEL AT 1405°F

Keys, J. J., Jr., and Krakoviak, A. I.

Nuclear Sci. and Eng., 9: 462-74 (Apr. 1961)

The effects on Inconel of the application of relatively high-frequency thermal oscillations are studied, under conditions such as to generate significant transient stress in the surface fibers. Thermal instabilities of this nature may be generated in the operation of certain types of nuclear reactors. Fatigue-type cracking is observed in 214 hr at 1.0 cps for a surface temperature amplitude of  $\pm 64^\circ\text{F}$  (17,800 psi maximum elastic surface stress); incipient cracking occurs in 23 hr at 0.4 cps for an amplitude of  $\pm 104^\circ\text{F}$  (31,300 psi). Application of  $\pm 46^\circ\text{F}$  surface temperature oscillations (12,800 psi) at 1.0 cps for 612 hr produces accelerated intergranular corrosion in a fused salt environment. These results are correlated in terms of the maximum calculated elastic surface stress.

NSA 15:17352

### 2.130 DEVELOPMENT OF WROUGHT COBALT-TUNGSTEN-BASE ALLOYS

E. F. Adkins, D. N. Williams, and R. I. Jaffee

(Cobalt, 1960, (8), 16-29)

The binary Co-W alloys investigated (contg. up to 35% W) proved extremely brittle, both in the soln.-treated and aged conditions. This was ascribed to the presence of impurities and to large grain-sizes. The effect of adding ternary elements was studied. Addn. of 5% Fe or 0.25% C to Co-25% W alloy increased the ductility from 2 to 11% elongation. An elongation of 16% was obtained after aging Co-25% W-5% Fe alloy. JSB

MA: 28:861

### 2.130 DMIC-42R (Also OTS-PB-161192R) 5/24/61 STANDARD DESIGNATION OF ALLOYS FOR AIRCRAFT AND MISSILES (REVISED)

A source list of government specification numbers and chemical compositions showing trade names and producers of high strength steels, austenitic, martensitic and precipitation hardened steels for low and high temperature applications. Also includes hot work die steels as well as nickel and cobalt base alloys.

- 2.130 ARDC-TR-59-66  
AIR WEAPONS MATERIALS APPLICATIONS HANDBOOK - METALS AND ALLOYS  
First Ed. December 1959, Syracuse Univ. Research Inst.  
ARDC. U. S. Air Force

A compilation of engineering, physical, and mechanical properties of commercially available structural alloys. The data presented includes minimum values of mechanical properties which are acceptable for design purposes, as well as specifying some for various wrought forms and heat treatment conditions. The coverage light weight alloys (Al, Mg, Ti) as well as the high temperature alloys is good. The low alloy steels and industrial types of alloy and carbon steels are not covered.

- 2.130 EFFECT OF ENVIRONMENT ON THE HIGH TEMPERATURE STRENGTH OF METALS.  
M. R. Achter, Naval Research Laboratory. NRL-5803

At elevated temperature, the strength of metals in vacuum or inert gases may be either higher or lower than that measured in a reactive gas. A mechanism to explain this reversal of the atmosphere effect has been proposed based on two competing processes. Adsorption of gas facilitates crack propagation while oxidation and similar reactions harden and strengthen a metal. The controlling process is determined by temperature and stress. Current studies designed to investigate the operation of these processes are presented.

A series of experiments has been conducted to investigate the effect of gas adsorption on crack propagation in creep and fatigue. Nickel is inert toward nitrogen, yet it is appreciably weaker in this gas than in vacuum. Metallographic studies show that this reduction in strength is related to an increase in number of intergranular cracks when the test is conducted in the gas. Changes in purity of both the metal and the gas affect the results and are indicative of the mechanism of the process. The results are discussed in terms of a model in which gas adsorption at the tip of a crack reduces the work required to break intermetallic bonds.

At sufficiently high temperatures, formation of load bearing oxide layers in grain boundary cracks, it is shown, can be an important source of oxidation strengthening. The measured rupture strength of sintered nickel oxide layers is of the right magnitude to account for some instances of strengthening and for the occurrence of anomalous fillet fractures in nickel creep specimens. See also NRL-5704 and NRL-5666

- 2.130 ASTM Special Technical Publ. #165  
Symposium on Effect of Cyclic Heating & Stressing on Metals at Elevated Temperatures  
57th Meeting, 6-17-54.

Theory of creep laws  
Austenitic steels, high temp. alloys

---

## 2.140 REFRACTORY METALS

- 2.140 CRITICAL COMPARISON OF Nb WITH OTHER MATERIALS FOR MISSILE AIRCRAFT & NUCLEAR APPLICATIONS.  
W. J. Harris, Jr., National Res. Council, Wash., D.C. Metallurgical Society Conference. D. F. Douglas and F. W. Kuirz, Editors, Interscience Publishers, 10, 3-10 (1961)

Above contains numerous articles on Nb. One is, "Oxidation Rate of Nb as a Function of Temperature and Pressure", by J. F. Brady and J. N. Ong, Jr., (Wash. Univ., St. Louis). 1961 BOOKS IN PRINT states METALLURGY OF COLUMBIUM by Douglass was in print.

- 2.140 BMI Report to AEC-NASA  
LIQUID METAL CORROSION MEETING, DECEMBER 1961 AT BNL

Engineering properties of potassium to 2100°F, analysis of Cb-1Zr included.  
TID-7626 (P.1) (AGN 2-2786)

- 2.140 WADC-TR-57-344 (Part V)  
DEVELOPMENT OF NIOBIUM BASE ALLOYS  
R. T. Begley, W. N. Platte, A. I. Lewis, and R. L. Ammon  
Westinghouse Research Lab. for ASD, USAF.  
Contract No. AF 33(616) 6258, Proj. 7351, Sept. 1961

The effect of oxygen and nitrogen additions on the hardness, workability, strain-hardening characteristics, and recrystallization behavior of niobium was determined. Nitrogen additions were found to be detrimental to cold rolling characteristics. Hardness, workability, and mechanical property data for Nb-C alloys were obtained. Grain boundary carbides were found to be very detrimental to cold workability. Carbon additions increased the ductile-brittle transition temperature range of niobium.

Mechanical property data were obtained for many binary, ternary and quaternary niobium base alloys. Re, W, and Mo additions increased the ductile brittle transition of niobium. A number of alloys were prepared by the consumable electrode arc melting process. Ingot breakdown was accomplished by high energy rate extrusion (Dynapak). The results of Dynapak extrusion were very encouraging.

Several high strength alloys were investigated. One alloy, Nb-10W-5V-1Zr, had excellent room temperature ductility and ultimate tensile strengths of 64,800 psi and 29,450 psi at 1205 C (2200 F) and 1315 C (2400 F) respectively.

Welding data for a number of Nb-base alloys are also presented.

- 2.140 Braze Bonding of Nb USP. 3046650, July 31, 1962

A method of brazing Nb parts together is described. The surface of the parts to be brazed together are placed in abutting relationship with a brazing alloy disposed adjacent. The alloy consists essentially of, by wt., 12 to 25% Nb; 0.5 to 5% Mo; and balance Zr. The alloy is heated to at least its MP to braze parts together. The brazed part is then cooled. The heating, melting and cooling takes place in inert atm.

NSA: 16-27584

- 2.140 AD 269975, 77p.  
WAL-TR766-3/1-3 DEVELOPMENT OF REFRACTORY COMPONENT MATERIALS  
SYSTEMS FOR SOLID PROPELLANT ROCKET MOTORS. Quart. Prog. Rept.  
4. July 20, 1961, H. Legett, et al.

Vapor deposition and techniques.

- 2.140 NIOBIUM-PROMISING, HIGH-TEMPERATURE REACTOR-CORE MATERIAL  
J. A. DeMastery and R. F. Dickerson (BMI)  
Nucleonics 18, No. 9, 87-90; 132; 134 (1960) Sept.

Physical properties of Cb as they are affected by oxygen. Corrosion tests of Cb in NaK.

NSA 14:23350

- 2.140 AEC-TR4867 Equilibria in the Nb-C-O System. Trans.

The thermal reduction of  $Nb_2O_5$  by C to  $NbO_2$  can take place from the thermodyn. standpoint at  $P = 1$  atm and  $T > 1230^\circ K$ . The subseq. conversion of  $NbO_2$  to NbO can be effected at  $P = 1$  atm and  $1650^\circ K$ . The conditions for reduction of NbO to the metal are less favorable than for the processes leading to formation of the carbides. If the change is designed for production of the metal, from the thermodyn. standpoint the 1st stage will be production of the highest carbide which is stepwise to the lowest carbide (or a solid sol.) and the metal. The exponents of the last stage of the process largely govern the conditions for realization of thermal reduction by C. At  $P = 1$  atm this process becomes feasible above  $2860^\circ K$  but it can be realized at  $1550^\circ C$  in vac.

NSA: 16-2208

- 2.140 The Phase Diagram of Nb-C System. H. Kimura and Y. Sasaki, Nat. Research Inst. for Metals, Science & Technics Agency, Tokyo. Trans. Japan Inst. Metals (Sendai 2:98-104, Apr. 61 (In English)).

This Nb-C system is investigated by melting point measurement, X-Ray analyses and microscopic exams. An equil. diagram up to 63.5 at. % C is shown. The limit of C sol. in Nb ( $\alpha$ ) phase lies about 2 at. % at 2000°C and it decreases abruptly as the temp. decreases. The Nb<sub>2</sub>C( $\beta$ ) phase has a very narrow range of homogeneity and the NbC ( $\gamma$ ) phase exists in a wide composition range from 41-50 at % C below 1400°C. 3 nonvariant reactions in this system are determined.

NSA: 16-1714

- 2.140 Diffusion of Nb and C into Nb and its Carbides. P. V. Gel'd and V. O. Lynbemov. Invest. Akad Nauk. SSSR Otdel Tekh Nauk. Met r Toplwo No. 6 119-26. (In Russian).

Nb<sup>95</sup> and C<sup>14</sup> were used in determining the diffusion of 1 Nb and C in metallic Nb and some of its carbides. The activation energies were determined for Nb diffusion in metal (85 K cal/g-at) and in its carbide NbC<sub>0.98</sub> (55 K cal/g - at) as well as for carbon in Nb (32 K cal/g-at) and in NbC<sub>0.98</sub>, NbC<sub>0.75</sub> and NbC<sub>0.5</sub> ( 32 to 33 K cal/g-at).

NSA: 16-12128

- 2.140 AD 256511 HIGH TEMPERATURE MATERIALS, THEIR STRENGTH, POTENTIALS AND LIMITATIONS  
Anon  
Syracuse University  
Proceedings of the 4th Sagamore Ordnance Materials Research Conf. Conduc. at Sagamore Conf. Center, Racquette Lake, New York. Aug. 21, 22, and 23, 1957 (Syracuse Univ. Research Inst. Syracuse, N.Y.) NP-6770, 358 p.

Thirteen papers are presented: Theory of High-Temperature Deformation of metals; Theory of High-Temperature Strength of Alloys; A survey of Recent Results on Experimental Determinations of Activation Energies for Creep; The Stability of Microstructures and Related Physical Properties at High Temp; The relation of Microstructure and High-Temperature Strength; Tensile Properties of Some Structural Sheet Materials Under Rapid Heating Conditions; Mechanical Properties of Structural Materials Under Conditions of Rapid Heating and Rapid Loading; Thermal Fatigue of Ductile Materials; Plastic Strain Absorption as a Criterion for High-Temp. Design; Strain Cycling and Thermal Fatigue; Design Under Conditions of Relaxing Complex Stress Concentrations; A Survey of the Effects of Nonsteady Load and Temperature Conditions on the Creep of Metals; and Chemistry at High Temperatures and Pressures. Data Tabulations are given on: creep activation energy of Al, Au, Cu, Fe, Ni, In, Cd, Pb, Zn, Mg, and Al-Mg; hardness of Cu vs coldwork; Al-Mg vs. strain rate; strength of steel vs. cold work and heat treatment; strength of Al-Cu-Mg vs. heat treatment; high-temperature properties of Co-Fe-Ni; tensile properties of steel, aluminum alloys and Inconel-X sheet under rapid heating conditions; and strain cycling and thermal stress fatigue of Inconel, stainless steel, various steels, Cr-Mo-Ni, Al, Cu, and Al-Mg.

- 2.140 ARF 2120-4 I.T.T. Armour Res. Found. Niobium Phase Diagrams - Manu. Report on Nb-C System. R. P. Elliott, May 6, 1959.

The Nb-C system has been determined by X-ray and metallog. exam. of sintered and arc cast alloys. 2 carbides exist - hexag. Nb<sub>2</sub>-C with a limited range of homogeneity, and cubic Nb-C with solubility range from 8.25 to 10.25 wt % C. Dilute alloys freeze by eutectic reaction at 2230°C.....

NSA: 13-16195

2.150 OTHER NONFERROUS METALS

To be expanded in the supplement.

2.160 NONMETALLIC MATERIALS

To be expanded in the supplement.

---

2.200 RELATIVE CORROSION RESISTANCE OF CONTAINMENT

MATERIALS FOR LIQUID METAL SERVICE

2.200 DMIC-169

THE EFFECT OF MOLTEN ALKALI METALS ON CONTAINMENT METALS  
AND ALLOYS AT HIGH TEMPERATURES

Amateau, M. F. (Battelle Memorial Inst.) Defense Metals Information Center, Columbus, Ohio). May 28, 1962. Contract AF 33(616)-7747. 54p.

A review is given on the corrosive effects of molten alkali metals on high temperature materials, and conclusions are drawn from existing data. Most of the high-temperature engineering metals such as refractory metals, nickel-base and cobalt-base superalloys, and the austenitic and ferritic stainless steels are sufficiently resistant to liquid sodium and NaK to be useful up to about 1600°F. The refractory metals and alloys are particularly susceptible to attack by sodium containing excessive amounts of oxygen. No material is truly corrosion resistant to Li, although the refractory metals Ta, Nb, and Mo do have some potential for high-temperature service in engineering applications. The nitrogen content of the Li is a particularly important factor in its corrosive effects. K, Rb, and Cs are somewhat less corrosive than the other alkali metals. The refractory metals and alloys are little affected by these liquid metals. Na and K can cause degradation of mechanical properties of containment materials, depending on the amount of oxygen and nitrogen found in the respective liquid metals. Also, the sliding and bearing properties of metals are generally affected adversely by the presence of pure molten metals (P.C.H.)

2.200

"Testing of Nb and Nb Alloys" D. L. Macleary Corrosion  
18 67t-69t 1962

Results of lab tests of Nb and Nb alloys as corrosion resistant materials are summarized .... The alloy Nb-1Zr was completely resistant to the various liquid metals except for welds that suffered intergranular corrosion. The Nb-7V alloy seemed to be more practical than Nb-10Ti-10 Mo alloy on basis of weldability and good high temperature stress property.

CA 56:9856h



2.200 ORNL 3313 Metals and Ceramics Div. Annual Progress Report for  
Period Ending May 31, 1962. Part II Materials Properties

Materials Compatibility. Selection of container materials compatible with alkali metals at elevated temperatures has been a continuing research program for several years. One area that received attention during the past year was an evaluation of methods for removing impurities from alkali metals. The use of metals such as Zr and Ti as getters was found to be the most practical and effective means of reducing  $O_2$  content. Research was initiated to determine the distribution coefficient of  $O_2$  between potential getter materials and alkali metals.  $O_2$  contamination of alkali metal was observed to increase the corr. of many container materials. In evaluating the accuracy of the existing analytical techniques for determining  $O_2$  in the alkali metals, none of the analytical methods investigated gave satisfactory results. Therefore a program was initiated to develop a method for determining  $O_2$  content of K. An investigation of the effect of  $O_2$  concentration of refractory metals on their corr. resistance to Li at elevated temperature showed that the pure metals Nb, Ta, V, and Zr to exhibit excellent resistance at temperatures even in excess of 800°C. When small quantities of  $O_2$  were added to either Nb or Ta, Li penetrated these metals very rapidly over a wide range of temperatures. No attack was observed when V and Zr were contaminated with O to levels of 2000 and 4000 ppm, respectively.

NSA 16:30167

2.200 REACTION OF CONSTRUCTION MATERIALS WITH LIQUID METALS  
V. I. Nikitin. Teploenergetika, No. 2, 90-2 (1962)  
(In Russian)

The utilization of liquid metals (Na, K, and NaK) as reactor coolants was analyzed, and the mechanism of their reaction with construction materials was studied. The properties of coolants and construction materials, the temperatures and temperature gradients in the system, the rate of flow, and the presence of admixtures are discussed. The corrosion factors for Bi and Pb depend on their affinity to simple diffusion while for Na and K, corrosion depends mostly on the amount of oxygen present. A table is included of maximum permissible temperatures for various construction materials, showing not more than 0.012 mm corrosion after 1000 hr in molten Na and Li. (R.V.J.)

NSA 16:32087

2.200 "Resist. of Various Materials to Attack by Molten  
Salts and Metals" A Lunden Corr. Science 1 No. 1 62-4 (1961)

In work with molten salts and metals, the container is often attacked by the melt. Pract. experience with some 30 melts is reviewed. A common observation was that the attack was strongest at the interface between melt and surrounding atm. Such attack is often due to compounds formed at cathode during electrolysis. In other cases the attack is located in a section where a compound with high reactivity was concerned due to relative mobility of ions.

CA 56:2274g

2.200 "The Behavior of Alkali Metal Towards Cu, Ag and Au"  
G. Kienest and J. Verma (U. of Munster, Westphalia, Germany)  
Z. Amorg. Allgem Chem 310, 143-69 (1961)

Abstract lists the intermetallic compounds formed and temperatures.

CA 56:13767h

2.200 PWAC-604 (Secret)  
Pratt and Whitney Aircraft Division, United Aircraft Corporation,  
Middletown, Connecticut  
Nuclear Propulsion Program Engineering Progress Report,  
October 1, 1960 - December 31, 1960. January 1961. 194p.  
... corrosion studies ... ACR 17:752

2.200 See Also: 1.410, 1.500, 1.520, 2.210 thru 2.240, 2.400, 3.400  
thru 3.440.

2.200 IS-190 (Uncl.)  
Ames Laboratory, Ames, Iowa  
Annual Summary Research Report in Engineering for July 1, 1959 -  
June 30, 1960. August 1960. 41p.  
. . . corrosion by liquid metals . . . NSA 15:5854

2.200 Tilting Capsule Tests in LMFE Fuel Solution  
(Final report) BAW-1252, E. J. Roz (April 1960)

2.200 Liquid and Vapor Alkali-Metal Corrosion (BMI)  
E. M. Simons, NASA TN-D-769, 1960

Data for NaK capsule, NaK loop, Na loop, Na purity, Na as a  
lubricant, K vapor, K liquid and vapor.

NSA 15:13279

2.200 BMI-1477 (Secret)  
Battelle Memorial Institute, Columbus, Ohio  
Recent Developments in Reactor Materials Technology.  
R. W. Dayton, et al., November 1960. 212p.  
. . . corrosion by liquid metals . . . NSA 17:398

2.200 BMI-1344 (Secret)  
Battelle Memorial Institute, Columbus, Ohio.  
Recent Developments in Reactor Materials Technology.  
R. W. Dayton and E. M. Simons. May 1959. 162p.  
. . . corrosion of metals by liquid metals . . .  
RL

2.200 Corrosion of Iron and Steels in Liquid Metals.  
I. Static Corrosion Test  
Imai, Y. and Ishizaki, T.  
Tohoku Univ., Sendai  
J. Atomic Energy Soc., Japan 2, 96-101 (1960), Feb.  
NSA 14:12859

The modes of attack by liquid metal are direct alloying, dis-solution,  
intergranular penetration, corrosion by contaminants, and others. Microscopic  
examination of metallographically polished surface was adopted to investigate  
the attack of liquid metals on iron and steels. The reliability of the experi-  
mental method, the effect of oxygen and the effect of stabilizer of oxygen  
were examined.

2.200 Liquid Metal Heat Transfer Media  
Kutateladze, S. S. et al.  
Translation of Atomnaya Energ. Suppl. No. 2, 1958  
New York, Consultants Bureau, Inc. 1959, 152 p.

The thirteen chapters in this volume cover the following subjects:  
basic properties of liquid metals, application of liquid metal heat transfer  
media hydraulic resistance in the flow of liquid metals, turbulent heat  
transfer in liquid metals, heat transfer during flow in tubes, heat transfer  
during the longitudinal flow around a plate, heat transfer during transverse  
flow around cylinders, heat exchange during free convection, heat transfer  
during vapor condensation, heat exchange during boiling, heat-exchanging  
equipment, stability of heat-resistant materials in liquid metals, and  
instrumentation

NSA 14:287

2.200 ACTION OF MOLTEN ALKALI OF LITHIUM, SODIUM, AND POTASSIUM ON  
NICKEL, COPPER, IRON AND STAINLESS STEEL  
Ye. I. Gurovich. Zhurnal Prikladnoy Khimii, Vol. 32, No. 4,  
pp. 817-822. 1959. Submitted January 28, 1958

2.200 MATERIAL AND CORROSION PROBLEMS IN A REACTOR WITH LIQUID METALS AS  
COOLANT. Willibald Machu. Atomkern-Energie 3, 94-6(1958)Mar.  
(In German).  
NSA 12:7491

- 2.200      Corrosion by Liquid Metals and Aqueous Solutions. P. R. Eisenberg, Paper from "Metals for Nuclear Reactors." American Society for Metals, Metals Park, Novelty, Ohio, 1959, p. 47-62.

Mass transfer and intergranular penetration in corrosion of Inconel and stainless steels by liquid metals. Reaction of impurities in liquid metal and purification techniques. Intergranular corrosion. Stress-corrosion cracking and galvanic corrosion of stainless steels by aqueous solutions at high temperatures. Static and dynamic testing. (R1, R2, R4, R6m:SS Ni-b)

Corrosion by liquid Hg

- 2.200      NAA-SR-3216, Secret, Atomics International Division, North American Aviation, Inc., Canoga Park, California. Nuclear Auxiliary Power Unit Development Program SNAP II. Bimonthly Progress Report for August-September 1958. H. M. Dieckamp. November, 1958.

... corrosion rates of stainless steel and Hastelloy B in lithium ... (check for NaK)      ACR 15:457

- 2.200      AD 256511  
PROGRESS REPORT NO. 38 FOR DECEMBER 1956 AND JANUARY 1957  
Posey, W. J. (Ed.)  
(Mine Safety Appl. Co., Callery, Penn.) NP-6209, 42p, (Feb. 13, 1957)

Tests are continuing on the 1000 and 3000 KW steam generators. Two tests were performed with B & W miniature boilers, and results are presented. Corrosion testing of reactor cladding and structural materials in biphenyl at 800°F and 300 psig has been completed. High velocity corrosion testing in isopropyl biphenyl has been completed. The solubilities at high temperatures and pressures of the gases, A, air, CH<sub>4</sub>, N<sub>2</sub> and H<sub>2</sub> in organic moderator coolants are presented.

- 2.200      AD 256511  
PROGRESS REPORT NO. 37 FOR OCTOBER AND NOVEMBER 1956  
Posey, W. J. (Ed.)  
(Mine Safety Appliances Co., Callery, Penn.) NP-6179, 60 p. (Dec. 13, 1956)

The operation of the 1000-kw heat transfer unit at high temperatures was demonstrated to aid development of components for such service and to add to the body of liquid metal technology, 3000-kq steam generator tests were made as part of a steam generator development. Research on liquid metal system components is reported. Thermal shock tests were made on a tee in the S2G system used to join two liquid metal streams of different temperatures. Experimentation in which results are evaluated by chemical or radiochemical techniques including experiments in the field of organics is reviewed. High velocity corrosion testing in biphenyl of reactor materials is reported.

- 2.200      AD 256511  
PROGRESS REPORT NO. 36 FOR AUGUST AND SEPTEMBER, 1956  
Posey, W. J. (Ed.)  
Mine Safety App. Co., Callery, Penn. NP-6132, 70 p. (Oct. 10, 1956)

Tests are continuing on the 3000 KW steam generator. The unit has been subjected to a life test at cyclic conditions. The test system is shown schematically. The cycle test has been completed on the evaporator for the 3000 KW steam generator. A complete operational history of the evaporator is given. Stress tests are continuing on a tee in the S2G system used to join to liquid metal streams of different temperatures. The work on nitriding of Be, 347 stainless steel and tool steel is complete; tables of corrosion rates of the three metals in liquid Na are presented. Methods of installing freeze seals and design of the seals are being investigated to prevent Na from being carried in the venting system of the S2G into the upper level reactor compartment. Radioactive lead experiments were continued.

- 2.200 METALLURGY DIVISION SEMIANNUAL PROGRESS REPORT FOR PERIOD ENDING OCTOBER 10, 1956  
Decl. with deletions Nov. 4, 1959. 231 p. Contract W-7405-eng-26.  
OTS. ORNL-2217 (Del.)

Progress is reported in corrosion studies of stainless steels, Nb, Zr, Al-Fe-Mo, Mo, Ni, alloys, and Al-Ni by various materials including Na, Na-K, Li, Rb, and fused salts. Corrosion studies in pump loops of various materials by liquid metals are reported.

NSA 14:12840

- 2.200 Selection of Canning Materials for Reactors Cooled by Sodium/Potassium and Carbon Dioxide.  
McIntosh, A. B. and K. Q. Bagley  
U. S. Atomic Energy Authority (Industrial Group), Calcheth, Lancs. England). J. Inst. Metals 84, 250-70 (1956). March.

Theoretical considerations and experimental investigations indicate such metals as beryllium, zirconium, niobium, vanadium, tungsten, and molybdenum will be used for canning materials provided difficulties in extraction and fabrications can be overcome.

- 2.200 HANDLING OF LIQUID-METAL COOLANTS  
W. H. Bruggeman and H. E. Stone  
The Reactor Handbook, Vol. 2, Engineering, Ch. 2-4, p. 287-310, 1955.

Covers: purification, effect of impurities, H<sub>2</sub> moderation, sampling, corrosion, and materials resistance to corrosion in Na-NaK. (10 references).

- 2.200 KAPL-1021  
D. B. Vail  
Compatibility of Materials in Liquid Metal; Second Report, January 1954.  
Contract W-31-109-Eng-52. 69 pages:  
U.S. Gov. Res. Repts. 29, No. 6,377

- 2.200 AERE-X/R-1806  
Cambridge (Univ.), England  
INTERACTIONS BETWEEN SOLID AND LIQUID METALS AND ALLOYS.  
V. W. Eldred. 1953. 242p.

This report was written in the early part of 1953 and was based on work carried out at Cambridge in the preceding three years.

A technique for carrying out long-term corrosion tests is described. It has been applied to the investigation of over forty systems involving pure metals in contact with liquid Bi, Cd, Pb, Hg, K, Na, Sn and Zn at temperatures up to 550°C for periods of contact up to 300 hr. A series of ferrous and non-ferrous alloys has also been investigated under similar conditions in contact with the same liquid discussed. Criteria for the classification of combinations of solid and liquid metals and alloys according to their corrosive behavior are put forward and applied to the systems investigated. The factors controlling the rate of solution of a solid metal in a liquid metal under various conditions are discussed theoretically in the light of the experimental results. The knowledge at present available with regard to metals and alloys manifesting a high corrosion resistance to liquid metals is considered and the characteristics of such systems are discussed. A method of predicting further systems of a similar character is suggested. (auth)

NSA 10-7696

- 2.200 TABLE: "RESISTANCE TO ATTACK BY LIQUID METALS"  
L. R. Kelman, W. D. Wilkinson, and F. L. Yagee  
Metal Progress 58 (868B). Dec. 1950
- 2.200 NAVEXOS-P-733  
RESISTANCE OF MATERIALS TO ATTACK BY LIQUID METALS  
L. R. Kelman, W. D. Wilkinson, and F. L. Yagee, 1950

2.210      MERCURY SERVICE

- 2.210      MATERIALS COMPATIBILITY WITH MERCURY AT TEMPERATURES BELOW 1000°F. J. J. Owens and J. F. Nejedlik (TAPCO) Presented on February 22 at the 1962 AIME Meeting (at New York City) "Corrosion by Metal Heat Transfer Liquids Symposium.

- a) Low Carbon, 5% Cr, and austenitic stainless steels to 1200°F in natural convection harps.
- b) Effects of various additives on the corrosion rate of low carbon steel.
- c) Bent reflux tubes of Pyrex at temperatures of 1000°F and internal Hg vapor at 180 psi.
- d) Two phase natural circulating type loops: ferritic and austenitic stainless steel, and Haynes 25 alloy (43 Ref.)

- 2.210      BNL-756  
LIQUID METAL RESEARCH AT NASA-LEWIS RESEARCH CENTER  
James P. Lewis, Lewis Research Center, Cleveland, Ohio  
Second Annual High Temperature Liquid Metal Heat Transfer Technology Meeting, BNL, May 17 and 18, 1962

The paper outlines the major liquid metals research and development efforts at Lewis Research Center. The work includes: a Two-Phase Sodium Loop for flashing sodium vapor; the Sodium Turbine Facility using refractory metals; Pump Test Facilities including one low pressure K pump and one high pressure Na pump; Alkali Metal Heat Transfer Facility using EM pumps and Cb-12r above 1500°F and type 316 stainless below; A Space Radiator and Condenser Facility using a NaK loop for boiling potassium; Bearing and Seal Studies using liquid Na environments; Mercury Programs relative to the radiator problem in zero gravity similar to SNAP VIII conditions; and several Materials Support Programs directed to advanced materials and refractory metals for all alkali metals, and Hg loop corrosion.

- 2.210      BNL-756  
HIGH TEMPERATURE BOILING MERCURY EXPERIMENT  
C. J. Baroczy, Atomics International  
Second Annual High Temperature Liquid Metal Heat Transfer Technology Meeting, BNL, May 17 and 18, 1962.

A description of experimental equipment and materials employed for Hg boiling and heat transfer work. The system was in design and ready for fabrication. Duplex tubes consisting of low carbon steels clad with Inconel X or with Haynes Alloy 25 were studied.

- 2.210      Duplex Tube for SNAP-8 Corrosion Loops, B. E. Farwell,  
7 May 1962. AGN-EDS-159, Aerojet-General Nucleonics, San Ramon, Calif.

This engineering data sheet covers 9Cr-1Mo steel tubing clad with Type 316 stainless steel for use in the SNAP-8 corrosion loops.

- 2.210      EVALUATION OF MATERIALS IN LIQUID AND GASEOUS MERCURY  
TAPCO  
(NASA-AEC Liquid Metal Corrosion Meeting, Dec. 1961 at BNL)  
Mercury Capsules and Loops - Results and Conclusions on Various Materials Including Wetting.  
TID-7626 (Part 1) (AGN Lib. 2-2786)

- 2.210 METALS COMPATIBILITY WITH MERCURY AT TEMPERATURES ABOVE 1000°F  
C. A. Barrett, W. Loudermilk, L. Rosenblum, C. Scheuermann, NASA-  
Lewis Research Center, ARS Space Power System Symposium,  
Santa Monica, Calif. Sept. 28, 1962.

Mercury reflux capsule corrosion tests were carried out at temperatures from 1000° to 1300°F and at times up to 1000 hours. The metals tested include the chromium steels, austenitic stainless steels, cobalt and nickel-based alloys, and refractory metals.

- 2.210 EVALUATION OF MATERIALS IN LIQUID AND GASEOUS MERCURY  
Owens, James J.  
Thompson Ramo Wooldridge Inc., Cleveland  
NASA-TN-D-769 (p. 51-5), 1961

Corrosion in a mercury environment at temperatures up to 1150°F was studied in association with the development of the SNAP-2 system. Both reflux capsules and natural circulation loops were used as testing methods. The relative corrosion of carbon steels, stainless steels, high-nickel alloys, Ti, Pt, Mn, Mg, Al, Zr, Ta, W, TiC, and Mo alloys was measured in mercury 900°F in 12-day tests. NSA 15:13277

- 2.210 NAA-SR-6306  
THE SNAP II POWER CONVERSION SYSTEM - TOPICAL REPORT NO. 14.  
MERCURY MATERIAL EVALUATION AND SELECTION. TAPCO ER-4461  
J. F. Nejedlik, April 10, 1961. Prepared under Subcontract  
N843FS-101221 for A.I.

The SNAP II system consists of a reactor heat source, a boiler, a mercury Rankine engine, an alternator, and a condenser. The corrosion and subsequent mass transfer resulting from the use of mercury as the thermodynamic working fluid have been under study for the past three years. This report presents the recent results of this study and discusses the corrosion mechanisms involved. (AGN Lib. 2-6456)

- 2.210 ER-4103  
THE SNAP II POWER CONVERSION SYSTEM TOPICAL REPORT No. 7.  
MERCURY MATERIALS EVALUATION AND SELECTION  
(TID-11,307), J. J. Owens et al., October, 1960. 143p.  
Thompson-Ramo-Wooldridge, Inc., Cleveland, Ohio.

This report presents the results of a two-year material compatibility study and discusses the corrosion mechanisms involved in a system in which mercury is the working fluid. Includes 35 references and 11 bibliographies. (AGN Lib. 2-5632)

NSA 15:21096

- 2.210 MND-P-2382  
SNAP I POWER CONVERSION SYSTEM MATERIALS DEVELOPMENT. TAPCO  
(ER-4057) June 20, 1960, V. F. Hambor and J. J. Owens

Metallic materials were investigated to determine their resistance to corrosive attack by Hg and the effect of mass transfer due to temperature and concentration gradients existing in the system. Materials evaluated included the refractory metals, carbon steels, and the 300 and 400 series stainless steels. As a result of the metallic materials effort, it was concluded that the corrosion contaminants generated produce a more severe problem than the loss of structural material. (AGN Lib. 1-978)

- 2.210 ANNUAL REPORT FOR 1960, METALLURGY DIVISION  
(Argonne National Lab., Ill.) ANL-6330, Contract W-31-109-eng-38.  
273p.

Includes Hg corrosion tests of type 304 stainless steel and Ti alloys at 350°C and 100 psia.

NSA 15:22692

2.210 MERCURY CORROSION OF TITANIUM AND TITANIUM ALLOYS AT ELEVATED TEMPERATURES.

J. Y. N. Wang, ANL  
(NASA-AEC Liquid Metal Corrosion Meeting, Dec. 1961 at BNL)

Mercury corrosion to 850°F. Paper presented is in connection with ANL Report 6261.

TID-7626 (P. 1) (AGN Lib. 2-2786)

2.210 High-Temperature Corrosion by Coolants (BNL)  
D. H. Gurninsky and C. J. Klamut, NASA TN D-769, 1960

Na and Hg corrosion, Zr inhibitors, solubility studies, and a variety of capsule and loop tests.

2.210 Solubilities of Selected Metals in Mercury: Hermex Process.  
A. F. Messing and O. C. Dean. Oak Ridge National Laboratory.  
U. S. Atomic Energy Commission, ORNL-2871, July 29, 1960, 21 p.  
(Available from U. S. Office of Technical Services, Washington 25, D. C.) \$.50.

The solubilities of U, Th, Ga, Sa and Nd in Hg are measured from room temperature to 356°C. Equations of the form  $\log \text{ of solubility } = a + b/T$  are developed and integral heats of solution are calculated. Solubilities of Ru, Pd, Zr and Mo in Hg containing excess U are also determined. 19 ref. (Pl2e; Hg, Th, U, Ga, Sa, Nd, Ru, Pd, Zr, Mo)

2.210 TID 3544  
Transport and Chemical Control in the Dissolution of Metals in Mercury. J. A. R. Bennett and J. B. Lewis. June 1957. 49p.  
(AERE-CE/R-1998). J. Chem. Phys. 55, 83-90(1958).  
NSA 12:17222

2.210 (Russian) Effect of Mercury on the Strength and Durability of Structural Materials. G. V. Karpenko, A. I. Yatsyuk and F. O. Yanchishin. Nauchnye Zapiski Instituta Mashinovedeniya i Avtomatiki (Akademiya Nauk USSR). Seria Mashinovedeniya, v. 6, 1957, p. 42-49.

Effect of Hg amalgamation on the mechanical properties of steel, brass and duralumin. Liquid Hg significantly lowered the tensile strength of brass test pieces (by 32%) while that of duralumin fell by 12%. The elongation figure of brass and duralumin fell to 0. Liquid Hg showed no effect on ground steel 30 Kh, or on Cu. Endurance under cyclical load test was sharply reduced. (Q-general; ST, Cu-n, Al-b, Hg)

2.210 MND-P-2382  
SNAP I POWER CONVERSION SYSTEM MATERIALS DEVELOPMENT.  
Period Covered: February 1, 1957 to June 30, 1959. TAPCO  
(ER-4057) V. F. Hambor and J. J. Owens

Investigations of materials for use in connection with the SNAP I mercury Rankine cycle power conversion system are discussed. Test programs are outlined and results are tabulated for each candidate material. Several non-metallic materials and processing procedures were developed which enabled uncooled high-performance electric machinery to operate at 550°F in mercury vapor.  
NSA 14:26041

2.210 INFLUENCE OF MERCURY UPON THE STRENGTH AND FATIGUE STRENGTH OF STRUCTURAL MATERIALS  
G. V. Karpenko, A. I. Yatsyuk and F. P. Yanchishin  
Nauchn. zap. in-ta Mashinoved i Avtomatiki. AN Ukr. SSR, Vol. 6, 1957

- 2.210 MATERIALS COMPATIBILITY WITH MERCURY AT TEMPERATURES BELOW 1000°F:  
James J. Owens and James F. Nejedlik, Thompson-Ramo-Wooldridge,  
AIME Annual Meeting, Feb. 22, 1962, New York City, New York

This paper presents the results of a materials program at Thompson-Ramo-Wooldridge covering a three-year study of mercury corrosion. Over ninety materials were screened and classified as to compatibility with liquid mercury at 900°F. Earlier work in connection with mercury boiler experiences is summarized and discussed. Experimental methods, including the new bent reflux tube method of corrosion testing, are reviewed. The temperature dependence of corrosion rate is presented for a number of select materials, and mechanisms of corrosion are suggested. Results of a limited study of effects of additives on corrosion are presented.

- 2.210 The Effect of Mercury on the Corrosion and Properties of Various Materials. Final Report. Part 3. A Survey of the Interactions of the Metallic Elements with Static Liquid Mercury at Room Temperature and 500 C.

Strachan, J. F. and Harris, N. L.  
General Electric Co., Ltd. Research Labs., Wembley, England  
19 July 1954, 45 p. Report No. 11,727  
AERE-X/R-1503  
NSA 13:12652

A general survey of the interactions, saturated solubility, and weight loss of most metals in mercury is presented. Determinations were made at room temperature and at 500 C with annealed and unstressed samples. The complexity of Hg attack is noted, and various methods of overcoming ambiguities are discussed in relation to experimental techniques. Data are tabulated.

- 2.210 Gurinsky, D. H., The Behavior of Materials in Aggressive Liquid Metals from IMD Special Report Series No. 2 - Nuclear Metallurgy 2-20-56

With reference to Hg, Pb, and Zn, there are six processes of mass transfer: 1) dissolution of metal into quiet boundary layer, 2) diffusion of dissolved metal into moving stream from a boundary layer, 3) transport by the moving stream, 4) nucleation of metal crystals in the stream, 5) growth of crystallites in the boundary layer accompanied by sintering, 6) transport of nuclei or crystallites into the boundary layer. Three variables of dynamic testing are: 1) alloying elements of test material, 2) additions to liquid, 3) time and temperature.

Addition agents can inhibit attack by formation of an insoluble layer of high stability on a solid surface, Zr, Ti, Cr, etc., carbides and nitrides.

Mg acts as oxidizing agent which conserves others.

Intermetallic compounds have the highest attack resistance.

- 2.210 THE INFLUENCE OF MERCURY ON ALUMINUM CORROSION. D.R. deHalas, May 25, 1953, 35 p. (HW-28129). \$0.30(OTS). (Hanford Works)

A series of tests was run to determine the effect of Hg and Hg<sup>+2</sup> at various concentrations, flow rates, and temperatures on Al corrosion in water. It was found that an ionic Hg concentration of 10 ppm or greater in the water caused severe pitting attack on the Al. Increasing the flow rate and increasing the ionic Hg concentration speeds up the attack. No attack was apparent with ionic Hg at concentrations 1 ppm or with metallic Hg at temperatures above 70°C. Visual observations and potential measurements showed that when the ionic Hg concentration of the water was 1 ppm at temperatures over 70°C the amalgam dissolved in the water faster than it could form on the Al. This observation led to the conclusion that Hg at these concentrations is not dangerous to Al at temperatures above 70°C.

- 2.210 See Also: 2.310, 3.410, and 4.100.



- 2.211      MATERIALS COMPATIBILITY WITH MERCURY AT TEMPERATURES BELOW 1000°F  
 James J. Owens and James F. Nejedlik  
 Thompson-Ramo-Wooldridge, Cleveland, AIME Annual Meeting,  
 Feb. 22, 1962, New York City

This paper presents the results of a materials program at Thompson-Ramo-Wooldridge covering a three-year study of mercury corrosion. Over ninety materials were screened and classified as to compatibility with liquid mercury at 900°F. Earlier work in connection with mercury boiler experiences is summarized and discussed. Experimental methods, including the new bent reflux tube method of corrosion testing, are reviewed. The temperature dependence of corrosion rate is presented for a number of select materials, and mechanisms of corrosion are suggested. Results of a limited study of effects of additives on corrosion are presented.

- 2.211      ORNL-2871  
SOLUBILITIES OF SELECTED METALS IN MERCURY : HERMEX PROCESS  
 A. F. MESSING and O. C. DEAN , ORNL, July 29, 1960

The solubilities of U, Th, Ga, Sm, and Nd in Hg were measured from room temperature to 356 degrees C. Also determined were solubilities of Ru, Pd, Zr, and Mo in Hg containing U.

- 2.211      CHEMICAL REACTIVITY.  
 G. E. Darwin and J. H. Buddery  
 Chap. 8 from "Beryllium. Metallurgy of the Rarer Metals No. 7."  
 Academic Press Inc., New York 3, 1960, p. 236-264.

The reaction of Be with pure reagents, including free energies of reaction and parabolic rate law constants; reaction with various container materials; corrosion in various environments. 63 ref. (P13, R-general; Be) (Corrosion by Hg)

- 2.211      The Attack of Unstressed Metals by Liquid Mercury. Strachan, J. F.  
 and N. L. Harris (General Electric Co., Ltd., Wembley, Eng.).  
 J. Inst. Metals 85, 17-24 (1956-57).

The saturated solubilities and weight losses at room temperature of most of the metallic elements in static liquid Hg have been determined, usually to 0.001%, by chemical analysis of the solutions and by weighing the specimens. The solubilities show a periodic relationship with the atomic number, and there are indications that this can be related to the inner electronic shell structure. In general, the solubilities of the B sub-group, elements exceed those of the true metals, while of this latter group the transition metals show the lowest values. When attack occurs, it involves wetting, surface and amalgamation, solution, and occasionally combination and intergranular penetration. The effect of oxide films has been investigated. The tests were conducted as far as possible in the absence of air, since oxidation brought some metals out of solution in Hg, leading to ambiguities. Exposure to air can result, for example, in a form of mass transfer. No significant changes take place in the mechanical properties of Fe, Mo, some steels, and Ni alloys after 2000 hr. in Hg at 500°C. Nickel suffers a decrease in maximum, stress, yield stress, and elongation of about 50%. Severe cavitation erosion of metals and alloys, normally resistant to Hg, occurs at room temperature on the application of 30 kc./s. ultrasonic vibrations.

NSA: 11-5313

- 2.212 SNAP-8 MATERIALS PROGRAM - QUARTERLY PROGRESS REPORT FOR PERIOD  
24 NOVEMBER 1962 TO 22 FEBRUARY 1963  
P. F. Young, Aerojet-General Nucleonics. March 1963. AN-869

Analytical and experimental work performed in support of the basic materials research for the SNAP-8 program is discussed. This work includes corrosion compatibility in mono- and bi-metallic capsules and advanced thermal convection capsules, studies of the solubility of certain elements in mercury, nuclear coordination of the irradiation of SNAP-8 materials and components, and creep strength testing of selected SNAP-8 materials. Results of these investigations are reported.

- 2.212 METALS COMPATIBILITY WITH MERCURY AT TEMPERATURES ABOVE 1000°F  
C. A. Barrett, W. Loudermilk, L. Rosenblum, C. Scheuermann, NASA-Lewis Research Center, ARS Space Power System Symposium, Santa Monica, Calif. Sept. 28, 1962.

Mercury reflux capsule corrosion tests were carried out at temperatures from 1000° to 1300°F and at times up to 1000 hours. The metals tested include the chromium steels, austenitic stainless steels, cobalt and nickel-based alloys, and refractory metals.

- 2.212 TID-7626 (Part 1)  
CORROSION OF LOW CARBON STEEL IN BOILING MERCURY  
A. Fleitman, A. Romano, and C. Klamut, Brookhaven National Laboratory

The primary purpose of this work is to investigate the corrosion resistance of low carbon steels to mercury and the effect of titanium or zirconium additions to mercury in retarding corrosive attack. Experiments on all liquid thermal convection loops and boiling-superheated mercury corrosion test loops, with and without Ti or Zr additions, were carried out in the temperature range of 1000° to 1300°F. The corrosion resistance of refractory metals and stainless steels were evaluated in miniature quartz loops.

- 2.212 ER-4103  
THE SNAP II POWER CONVERSION SYSTEM TOPICAL REPORT No. 7  
MERCURY MATERIALS EVALUATION AND SELECTION  
(TID-11,307), J. J. Owens et al., October, 1960. 143p.  
Thompson-Ramo-Wooldridge, Inc., Cleveland, Ohio

This report presents the results of a two-year material compatibility study and discusses the corrosion mechanisms involved in a system in which mercury is the working fluid. Includes 35 references and 11 bibliographies. (AGN Lib. 2-5632)

- 2.212 THE BEHAVIOR OF IRON AMALGAM DURING TEMPERING  
Gerhard Jangg, Erich Fitzer, Otto Adlhart, and Hans Hohn (Tech. Hochschule, Vienna). Z. Metallk 49, 557-62(1958).--

Iron has only a very small solubility in Hg so that iron amalgams are actually iron suspensions in Hg. Methods for the iron determination in the amalgam are described. If the iron concentration is high, the procedure consists in carefully evapg. the Hg in a H atm. and weighing of the iron residue. For low iron concentrations wet chem. methods are used consisting in selectively dissolving the iron with HCl under oxidizing conditions (H<sub>2</sub>O<sub>2</sub>). In freshly prepared amalgam an iron particle size of 2 to 10 predominates. During aging an increase to a size of 25 takes place. This aging effect can be sped up through heating of the amalgam to 400°. If higher temperatures are employed, particles of over 50 are formed. This heating effect can be advantageously used to improve the poor filtering characteristic of the amalgam so that an amalgam which was preheated to 500° filters almost as fast as pure Hg. Impurities such as Al which are soluble in Hg and have strong affinity to oxidize the iron in the amalgam catalytically, resulting, after some time in complete disintegration into Hg and Fe oxides. CA53-3004a

2.213 Austenitic Steels and High Temperature Alloys

- 2.213 MATERIALS COMPATIBILITY WITH MERCURY AT TEMPERATURES BELOW 1000°F  
J. J. Owens and J. F. Nejedlik (TAPCO) Presented on February 22  
at the 1962 AIME Meeting (at New York City), "Corrosion by Metal  
Heat Transfer Liquids Symposium."

- a) Low Carbon, 5% Cr, and austenitic stainless steels to  
1200°F in natural convection harps.
- b) Effects of various additives on the corrosion rate of  
low carbon steel.
- c) Bent reflux tubes of Pyrex at temperatures of 1000°F and  
internal Hg vapor at 180 psi.
- d) Two-phase natural circulating type loops: ferritic and  
austenitic stainless steel, and Haynes 25 alloy (43 Ref.)

- 2.213 NAA-SR-6306  
THE SNAP II POWER CONVERSION SYSTEM - TOPICAL REPORT NO. 14.  
MERCURY MATERIAL EVALUATION AND SELECTION. TAPCO ER-4461  
J. F. Nejedlik, April 10, 1961. Prepared under Subcontract  
N843FS-101221 for A.I.

The SNAP II system consists of a reactor heat source, a boiler,  
a mercury Rankine engine, an alternator, and a condenser. The corrosion  
and subsequent mass transfer resulting from the use of mercury as the  
thermodynamic working fluid have been under study for the past three years.  
This report presents the recent results of this study and discusses the  
corrosion mechanisms involved. (AGN Lib. 2-6456)

- 2.213 NASA-TN-D-769  
EVALUATION OF MATERIALS IN LIQUID AND GASEOUS MERCURY  
Owens, James J.  
Thompson-Ramo-Wooldridge, Inc., Cleveland  
(p. 51-5), 1961

Corrosion in a mercury environment at temperatures up to 1150°F  
was studied in association with the development of the SNAP II system.  
Both reflux capsules and natural circulation loops were used as testing  
methods. The relative corrosion of carbon steels, stainless steels, high-  
nickel alloys, Ti, Pt, Mn, Mg, Al, Zr, Ta, W, TiC, and Mo alloys was  
measured in mercury 900°F in 12-day tests.

NSA 15:13277

- 2.213 ER-4103  
THE SNAP II POWER CONVERSION SYSTEM TOPICAL REPORT No. 7  
MERCURY MATERIALS EVALUATION AND SELECTION  
(TID-11,307), J. J. Owens et al., October, 1960. 143p.  
Thompson-Ramo-Wooldridge, Inc., Cleveland, Ohio

This report presents the results of a two-year material compati-  
bility study and discusses the corrosion mechanisms involved in a system  
in which mercury is the working fluid. Includes 35 references and 11 biblio-  
graphies. (AGN Lib. 2-5632)

NSA 15:21096

- 2.213 CF-51-9-152  
Oak Ridge National Lab., Tennessee  
Effect of Mercury on the Corrosion of Type 309 SCb stainless steel  
in Acid Nitrate Solutions by Culler, F. L. Sept. 29, 1951. Decl.  
Feb. 20, 1957. 3p. Contract W-7405-eng-26.

NSA: 11-7608

2.213      See Also: 2.210

2.213      KAPL-M-WLF-5

Examination of the Natural Circulation Steam Generator From the Liquid Metal Heat Transfer Test Facility at Alplaus, N. Y.  
Callahan, E. J. and W. L. Fleischmann

September 12, 1953. Changed from Official Use Only  
Oct. 8, 1956, 35 p. Problem No. 70: Investigation of the Causes of Cracking in the Natural Circulation. Contract  
W-31-109-Eng-52

The first structural failure of a heat exchanger in the Alplaus liquid metal system is discussed. The metallurgical examination revealed failure of two Type 347 stainless steel tubes (NaK outside, mercury inside) and two tube sheets. The location of the failure was confined to the hot end and the area around these two hottest tubes. Judging by the fracture appearance, the majority of the cracks were caused by thermal cycling. Further studies are under way to establish more definitely the cause of the failure.

NSA 11:3791

---

2.214      Nickel and Cobalt Base Alloys

2.214      MATERIALS COMPATIBILITY WITH MERCURY AT TEMPERATURES BELOW 1000°F

James J. Owens and James F. Nejedlik  
Thompson-Ramo-Wooldridge, Cleveland, AIME Annual Meeting,  
Feb. 22, 1962, New York, City

This paper presents the results of a materials program at Thompson-Ramo-Wooldridge covering a three-year study of mercury corrosion. Over ninety materials were screened and classified as to compatibility with liquid mercury at 900°F. Earlier work in connection with mercury boiler experiences is summarized and discussed. Experimental methods, including the new bent reflux tube method of corrosion testing, are reviewed. The temperature dependence of corrosion rate is presented for a number of select materials, and mechanisms of corrosion are suggested. Results of a limited study of effects of additives on corrosion are presented.

2.214      EVALUATION OF MATERIALS IN LIQUID AND GASEOUS MERCURY

Owens, James J.  
Thompson-Ramo-Wooldridge Inc., Cleveland  
NASA-TN-D-769 (p. 51-5), 1961

Corrosion in a mercury environment at temperatures up to 1150°F was studied in association with the development of the SNAP-2 system. Both reflux capsules and natural circulation loops were used as testing methods. The relative corrosion of carbon steels, stainless steels, high-nickel alloys, Ti, Pt, Mn, Mg, Al, Zr, Ta, W, TiC, and Mo alloys was measured in mercury 900°F in 12-day tests.

NSA 15:13277

2.214      NAA-SR-6306

THE SNAP II POWER CONVERSION SYSTEM - TOPICAL REPORT NO. 14.  
MERCURY MATERIAL EVALUATION AND SELECTION. TAPCO ER-4461  
J. F. Nejedlik, April 10, 1961. Prepared under Subcontract  
N843FS-101221 for A.I.

The SNAP II system consists of a reactor heat source, a boiler, a mercury Rankine engine, an alternator, and a condenser. The corrosion and subsequent mass transfer resulting from the use of mercury as the thermodynamic working fluid have been under study for the past three years. This report presents the recent results of this study and discusses the corrosion mechanisms involved. (AGN Lib. 2-6456)

- 2.214 ER-4103  
THE SNAP II POWER CONVERSION SYSTEM TOPICAL REPORT NO. 7.  
MERCURY MATERIALS EVALUATION AND SELECTION  
(TID-11,307), J. J. Owens et al., October, 1960. 143p.  
Thompson-Ramo-Wooldridge, Inc., Cleveland, Ohio.

This report presents the results of a two-year material compatibility study and discusses the corrosion mechanisms involved in a system in which mercury is the working fluid. Includes 35 references and 11 bibliographies. (AGN Lib. 2-5632)

NSA 15:21096

- 2.214 THE EFFECT OF MERCURY ON THE CORROSION AND PROPERTIES OF VARIOUS MATERIALS. FINAL REPORT. PART 3. A SURVEY OF THE INTERACTIONS OF THE METALLIC ELEMENTS WITH STATIC LIQUID MERCURY AT ROOM TEMPERATURE AND 500°C  
Strachan, J. F. and Harris, N. L.  
General Electric Co., Ltd. Research Labs., Wembley, England  
19 July 1954, 45 p. Report No. 11, 727  
AERE-X/R-1503  
NSA 13:12652

A general survey of the interactions, saturated solubility, and weight loss of most metals in mercury is presented. Determinations were made at room temperature and at 500 C with annealed and unstressed samples. The complexity of Hg attack is noted, and various methods of overcoming ambiguities are discussed in relation to experimental techniques. Data are tabulated.

---

2.215 Refractory Metals

- 2.215 ER-5302  
SUNFLOWER SOLAR RANKINE SYSTEM MERCURY CORROSION AND CORROSION PRODUCT SEPARATOR STATUS SUMMARY (TAPCO) April 16, 1963  
Presented at NASA-Lewis Research Center on the general topic of Mercury Corrosion and Corrosion Product Trapping Experience at TAPCO.

The report has been centered primarily around the effects and test results which have been noted to date on the mercury Rankine cycle systems. Corrosion product separators are discussed and their results analyzed. High temperature Ni and Co base alloys as well as refractory metals such as W, Ta, Cb, and Cb-Ti alloys are included.

- 2.215 TID-7626 (Part 1)  
VAPOR-LIQUID CORROSION STUDIES IN MERCURY AND SODIUM SYSTEMS  
A. Fleitman, A. Romano, and C. Klamat (BNL)(NASA-AEC Liquid Metal Corrosion Meeting, Dec. 1961, at BNL)

Corrosive behavior of liquid Hg and Hg vapor from 600 to 1400°F, and of liquid Na and Na vapor from 1500 to 2400°F. Refractory metals including Cb-1Zr alloy are under investigation in loops and capsules. Wetting and inhibitors tested. (AGN Lib. 2-2786)

- 2.215 TID-7626 (Part 1)  
LIQUID METAL RESEARCH  
NASA-Lewis (NASA-AEC Liquid Metals Corrosion Meeting, Dec. 1961 at BNL)

Hg corrosion loops and capsules; includes solubility study.  
(AGN Lib. 2-2786)

- 2.215 See Also: 2.210 and 2.211
-

- 2.216 SOME OBSERVATIONS ON THE INHIBITION OF MERCURY ATTACK ON TITANIUM AND ITS ALLOYS. James Y. N. Wang, Argonne National Laboratory, 12th Annual AEC Corrosion Symposium, May 20-22, 1963, Castlewood, Pleasanton, California.

Nitrided surfaces of titanium and its alloys have been found to be unaffected by liquid mercury at 538°C. At this temperature, mercury vapor attacks certain alloys while others are immune. For instance; the corrosion of a nitrided Ti-8 Mn alloy was found to be insignificant; however, severe corrosion occurs at the nitrided layer of a Ti-7 Al-12 Zr alloy. This corrosion behavior leads one to believe in the probable importance of the chemical and structural nature of these layers.

A study of the effect of metallic additives to mercury on the corrosion resistance of titanium at 538°C has also been made. It is shown that a saturated mercury solution of zirconium or nickel exerts a strong influence in reducing the corrosion effect. The corrosion products formed an adherent protective film which appeared to be consistent with Ti-Zr-Hg or Ti-Ni-Hg compound. These films are thermodynamically stable in the testing environment and may act as a diffusion barrier between solid and liquid.

New titanium alloys and loop test data are presented.

- 2.216 ANL-6485  
Argonne National Laboratory, Illinois  
REACTOR DEVELOPMENT PROGRESS REPORT, DECEMBER 1961.  
January, 1962. 63 p.

... Hg corrosion attack on titanium ... NSA 16:12649

- 2.216 CORROSION OF TITANIUM AND TITANIUM ALLOYS IN MERCURY AT ELEVATED TEMPERATURES  
James Y. N. Wang, Argonne National Laboratory  
BNL 728(c-33) 1962

A survey of sixteen commercially available Ti and Ti alloys has been made in Hg. The use of Zr in Hg is mentioned.

- 2.216 EMBRITTLMENT OF COPPER ALLOYS BY MERCURY SOLUTIONS  
R. Rosenberg and I. B. Cadoff, New York University  
BNL 728(c-33) 1962

Report includes an evaluation of Hg-Zn solutions used as the wetting agent.

- 2.216 Mercury Embrittlement of Ti alloy, RC 130A. H.P. Leighley Jr. Miss. School Mines Rolla Mo.) Trans. AIME 221 408-9(1961)

Specimens cut from RC 130A sheet were stressed and covered with Hg confined by a plastic ring. A hole was drilled in the specimen through the pool of Hg. When the stress was high enough, fracture occurred instantaneously with drilling. By repetition, the threshold stress can be detected. Hg embrittlement causes a reduction in UTS from 132 KSI to ~15.7 KSI. The drilling of the holes in absence of Hg does not affect properties. The shear planes are at ~45° to the stress angle. Only at the brittle region.

- 2.216 MERCURY-CORROSION WORK AT ANL, FOR NAVAL REACTOR  
Report WAPD-3, Jan. 1, 1950, p. 157

Zirconium in mercury, a distinct amalgam layer formed on Bureau of Mines Zr after 330 hr at 316°C (600°F).

- 2.216 FAILURE OF METALS IN CONTACT WITH LIQUID METAL  
G. V. Karpenko  
(NP-tr-581) Translated from Priklad. Mekh. 3: No. 1, 13-19 (1957).  
12 p.

A study was made of the influence of Hg on the durability of polished and rolled specimens of brass and duralumin to cyclic stresses at room temperature. The durability of untreated brass specimens was greater than treated specimens tested in air and Hg, except for rolled specimens tested in air. The durability of the untreated duralumin was greater for polished specimens tested in air and rolled specimens tested in Hg, while the durability was greater for treated polished specimens tested in Hg and treated rolled specimens tested in air. Results do not confirm the diffusion hypothesis of the mechanism of failure of stressed metal under the action of liquid metal. (B.O.G.)

NSA 15:16076

2.217 Nonmetallic Materials

- 2.217 Vapor-Liquid Corrosion Studies in Mercury and Sodium Systems  
A. Fleitman, A. Romano, and C. Klamat (BNL) (NASA-AEC Liquid Metal Corrosion Meeting Dec. 1961 at BNL)

Corrosive behavior of liquid Hg and Hg vapor from 600-1400°F, and of liquid Na and Na vapor from 1500-2400°F. Refractory metals including Cb-1Zr alloy are under investigation in loops and capsules. Wetting and inhibitors tested. TID-7626 (Part 1) (AGN Lib. 2-2786)

- 2.217 MND-P-2382  
SNAP 1 POWER CONVERSION SYSTEM MATERIALS DEVELOPMENT  
V. F. Hambor and J. J. Owens  
The Martin Co. Purchase Order OE-0101, TAPCO, ER-4057, June 1960

Because of the environmental conditions imposed on the SNAP 1 Power Conversion System, it was necessary to conduct a program to determine the materials to be used in fabricating the system. The very small operating clearances resulting from minituration of the components made it imperative that formation of any corrosion products be minimized to avoid plugging of small flow passages and interference between parts. In addition, nonmetallic materials had to be evaluated to provide a reliable insulation system for the electrical components and a method for insuring that mercury did not enter the stator windings of the alternator.

Metallic materials were investigated to determine their resistance to corrosive attack by mercury and the effect of mass transfer due to temperature and concentration gradients existing in the system. Materials evaluated included the refractory metals, carbon steels, and the 300 and 400 series stainless steels. As a result of the metallic materials effort, it was concluded that the corrosion contaminants generated produce a more severe problem than the loss of structural material. At 750 to 800°F, most steels were satisfactory, but at 1000°F, the alloys containing Ni were attacked by Hg, but type 446 steel was resistant.

A nonmetallic materials program was conducted to develop suitable insulation and sealing materials for the alternator stator. It was established that the materials and fabrication techniques developed could satisfactorily protect the stator in the SNAP 1 environment.

- 2.217 To be expanded in the supplement.

- 2.220 Alkali-Metal Corrosion Studies  
E. E. Hoffman, ORNL-3313, Annual Report, May 1962

The physical properties of alkali metals make them highly desirable as nuclear coolants and heat-transfer media. Unfortunately, the hazards associated with any leakage of these fluids as extensive use. In most cases, utilization has been limited to those systems in which no other heat-transfer fluid meets the requirements. For several years this group has been studying various facets of the corrosion problems inherent in containing flowing alkali metals at high temperature. During the past year, investigations were conducted on the optimum techniques for removing nonmetallic impurities and the development of suitable analytical procedures for determining the purity of alkali metals, on the relation between oxygen distribution and corrosion of refractory metals in contact with lithium, and on the use of a nickel-base alloy for containing boiling potassium.

- 2.220 REACTION OF CONSTRUCTION MATERIALS WITH LIQUID METALS  
Nikitin, V. I., Teploenergetika, No. 2, 90-2 (1962) In Russian.

The utilization of liquid metals (sodium, potassium, and their alloys, bismuth, and lead) as reactor coolants was analyzed, and the mechanism of their reaction with construction materials was studied. The properties of coolants and construction materials, the temperatures and temperature gradients in the system, the rate of flow, and the presence of admixtures are discussed. The corrosion factors for bismuth and lead depend on their affinity to simple diffusion while for sodium and potassium, corrosion depends mostly on the amount of oxygen present. A table is included of maximum permissible temperatures for various construction materials, showing not more than 0.012 mm corrosion after 1000 hr, in molten sodium and lithium. (R.V.J.)

- 2.220 ORNL-3226 (Secret)  
Oak Ridge National Laboratory, Tennessee  
AIRCRAFT NUCLEAR PROPULSION PROGRESS REPORT FOR PERIOD OF MAY 1, 1961 TO JUNE 30, 1961. December, 1961. 112 p.

...Li corrosion...potassium compatibility...

ACR 18:377

- 2.220 ORNL-3074  
Oak Ridge National Laboratory, Tennessee  
OAK RIDGE NATIONAL LABORATORY STATUS AND PROGRESS REPORT, JANUARY 1961. February, 1961. 42 p.

...compatibility with K...

ACR 17:609

- 2.220 TID-7626 (Part I)  
ALKALI-METAL CORROSION STUDIES AT ROCKETDYNE  
W. T. Chandler (NASA-AEC Liquid-Metals Corrosion Meeting. Dec. 1961 at BNL)

Loop and capsule tests utilizing Na, K, and includes data on corrosion of refractory metals. (ACN Lib. 2-2786)

- 2.220 See Also: 2.240, 2.320, 3.420, and 4.200.



- 2.220 ENGINEERING PROPERTIES OF POTASSIUM  
A. W. Lemmon, Jr., W. H. Mink, H. W. Deem, and E. H. Hall  
Battelle Memorial Institute  
Notes on Conference on Properties of Alkali Metals at BMI April 1961

The thermodynamic properties of K, and a study of materials of containment which includes Cb-1Zr alloy.

- 2.220 TID-7626 (Pt. 1)  
POTASSIUM CORROSION STUDIES  
E. A. Kovacevich, AiResearch  
(NASA-AEC Liquid-Metals Corrosion Meeting, December 1961 at BNL)

Loop and capsule tests of various materials with liquid and vapor K at 1000-2000°F. Results included in report. (AGN Lib. 2-2786)

- 2.220 ALKALI LIQUID METAL TEST ACTIVITIES (AiResearch)  
E. A. Kovacevich, NASA-TN-D-769, 1960

Four categories of materials were evaluated in a K environment, (1) turbine, (2) alternator, (3) container, and (4) bearing materials.

- 2.220 NP-10,147 Uncl.  
Rocketdyne Division, North American Aviation, Inc., Canoga Park, California  
COMPATIBILITY OF MATERIALS WITH HIGH TEMPERATURE POTASSIUM, THIRD QUARTERLY PROGRESS REPORT, NOVEMBER 1, 1960 THROUGH JANUARY 31, 1961. March, 1961. 62 p. (NAA-R-2617-3)

NSA 15:18505

- 2.220 NP-10,005 Uncl.  
Rocketdyne Division, North American Aviation, Inc., Canoga Park, California.  
COMPATIBILITY OF MATERIALS WITH HIGH TEMPERATURE POTASSIUM, SECOND QUARTERLY PROGRESS REPORT, AUGUST 1 THROUGH OCTOBER 31, 1960. November 1960. 31 p. (NAA-R-2617-2)

NSA 15:16060

- 2.220 Some Factors Influencing the Compatibility of Metals with Sodium, Potassium, and Uranium  
Mc Intosh, A. B., Broadley, J. S. and Bagley, K. Q.  
Great Britain Culcheth Labs., Culcheth, Lance, England  
RDB(C)/TN-31 April 29, 1953, 38p. (FRDC/P-27)  
NSA 13:20183

The various factors which may influence the compatibilities of metals with sodium, potassium, and uranium are considered. Where possible, these have been assessed using data which can be calculated or are already available in the literature. By studying the relation between the position of metals in the periodic classification and their compatibilities, it is shown that the most likely constructional metals for a fast reactor fuel element container are to be found in Groups IV, V, and VI.

---

2.221 Pure Metals See: 2.220

2.222 Ferritic and Martensitic Steels

See: 2.220 and 2.242

---

2.223 DMIC-169

THE EFFECT OF MOLTEN ALKALI METALS ON CONTAINMENT METALS  
AND ALLOYS AT HIGH TEMPERATURES

Amateau, M. F. (Battelle Memorial Inst.) Defense Metals Information Center, Columbus, Ohio). May 28, 1962. Contract AF 33(616)-7747. 54p.

A review is given on the corrosive effects of molten alkali metals on high temperature materials, and conclusions are drawn from existing data. Most of the high-temperature engineering metals such as refractory metals, nickel-base and cobalt-base superalloys, and the austenitic and ferritic stainless steels are sufficiently resistant to liquid sodium and NaK to be useful up to about 1600°F. The refractory metals and alloys are particularly susceptible to attack by sodium containing excessive amounts of oxygen. No material is truly corrosion resistant to Li, although the refractory metals Ta, Nb, and Mo do have some potential for high-temperature service in engineering applications. The nitrogen content of the Li is a particularly important factor in its corrosive effects. K, Rb, and Cs are somewhat less corrosive than the other alkali metals. The refractory metals and alloys are little affected by these liquid metals. Na and K can cause degradation of mechanical properties of containment materials, depending on the amount of oxygen and nitrogen found in the respective liquid metals. Also, the sliding and bearing properties of metals are generally affected adversely by the presence of pure molten metals (P.C.H.)

2.223 TID-7626 (Part 1)

LIQUID METAL INVESTIGATIONS

J. W. Semmell, Jr. (GE-FPLD)

(NASA-AEC Liquid-Metals Corrosion Meeting, Dec. 1961 at BNL)

Na and K in testing up to 1850°F for 1) heat transfer studies, 2) operation of a turbine with K vapor, 3) analysis of liquid metals, 4) development of materials for liquid metal containment, 5) the study of corrosion phenomena. Data included in report. (AGN Lib. 2-2786)

2.223 TID-7626 (Part 1)

ALKALI-METAL CORROSION STUDIES AT ROCKETDYNE

Dr. W. T. Chandler (NASA-AEC Liquid-Metals Corrosion Meeting, Dec. 1961 at BNL)

Loop and capsule tests utilizing Na, K, and includes data on corrosion of refractory metals.

(AGN Lib. 2.2786)

2.223 ORNL-2988

MATERIALS COMPATIBILITY

E. E. Hoffman, W. H. Cook, et. al.

Studies to determine the compatibility of type 304 stainless steel and beryllium in a NaK environment were conducted at 1112, 1292, and 1472°K. A program to investigate the compatibility of boiling potassium with several potential container materials at 1600°F. Refluxing K capsule tests with metallographic and weight-change data is presented. A boiling-K-type 316 stainless steel loop test for 200 hrs at 1500°F resulted in no attack on the loop. An additional test was run for 1800 hours at 1600°F. Tests include the solubility of container materials in an alkali metal and the rate of solution of the container material. Thermal convection loop studies were being planned.

NSA 15:537

2.223

ENGINEERING PROPERTIES OF POTASSIUM

2nd Quarterly Report, Covering Period, Jan 1 through March 31, 1961. A. W. Lemmon, Jr. (BMI) (NP-10324) Apr 30, 1961

2.224 THE EFFECT OF MOLTEN ALKALI METALS ON CONTAINMENT METALS AND ALLOYS AT HIGH TEMPERATURES

Amateau, M. F.

Defense Metals Information Center, Battelle Memorial Institute  
DMIC Report 169, May 28, 1962. 54 p.

Extensive review of literature on the effects of Na and NaK alloys, liquid Li and liquid and gaseous K, Rb and Cs on the corrosion and sliding and bearing properties of pure metals and alloys including stainless steel, superalloys and refractory metals. Topics include types of liquid-metal corrosion, factors affecting liquid-metal corrosion and techniques for investigating such. 71 ref. (R6m, 2-62; SGA-h, SS, EG-d37)

2.224 COMPATIBILITY OF INCONEL WITH BOILING ALKALI METALS

D. H. Jansen and E. E. Hoffman, Oak Ridge National Laboratory  
Am. Inst. Mining, Met., and Pet. Engrs., Annual Meeting,  
New York, February 18 - 22, 1962.

Nickel-base alloys have numerous physical and mechanical properties which make them potentially useful for containing alkali metals at elevated temperatures. Alkali metals are currently being considered as working fluids for Rankine-cycle Turbo-generator systems for space power applications. The results of studies to determine the compatibility of Inconel with boiling rubidium, sodium, and potassium at temperatures up to 1600°F for several thousand hours are presented.

2.224 TID-7626 (Part 1)

LIQUID METAL INVESTIGATIONS

J. W. Semmel, Jr. (GE-FPLD)

(NASA-AEC Liquid-Metals Corrosion Meeting, Dec. 1961 at BNL)

Na and K in testing up to 1850°F for 1) heat transfer studies, 2) operation of a turbine with K vapor, 3) analysis of liquid metals, 4) development of materials for liquid metal containment, 5) the study of corrosion phenomena. Data included in report. (AGN Lib. 2-2786)

2.224 METALLURGY DIVISION ANNUAL PROGRESS REPORT, MAY 31, 1961  
ORNL-3160, pp. 73-74.

(a) Refluxing capsules, 500 and 1000 hours at 1500 and 1600°F on Inconel, Haynes Alloy # 25, types 310 and 316; types 316 shows best resistance to attack by potassium.

(b) 316-K loop, 3000 hours, 1600°F, results of metallographic examination, chemical results.

2.224 TID-7626 (Pt. 1)

POTASSIUM CORROSION STUDIES

E. A. Kovacevich, AiResearch

(NASA-AEC Liquid Metals Corrosion Meeting, Dec. 1961 at BNL)

Loop and Capsule corrosion tests -liquid and vapor potassium at 1000 - 2000°F. Materials included: Hasteloy X, tungsten, Cb and Mo alloys and several non- metals. Results included in report.

2.224 RESISTANCE OF MATERIALS TO ATTACK BY LIQUID METAL

(ANL-4417) July 1950

L. R. Kelman, W. D. Wilkenson, and F. L. Yagee (ANL)

2.225      Refractory Metals

- 2.225      NIOBIUM ALLOY - BOILING POTASSIUM LOOP EXPERIMENTS.  
Classified Paper. D. H. Jansen and E. E. Hoffman (ORNL).  
Presented at the 12<sup>th</sup> Annual AEC Corrosion Symposium, May 20-22,  
1963, Castlewood, Pleasanton, California
- 2.225      OXYGEN PARTITIONING IN POTASSIUM-OXYGEN REFRACTORY METAL SYSTEMS  
A. P. Litman and J. R. DiStefano, Oak Ridge National Laboratory,  
12<sup>th</sup> Annual AEC Corrosion Symposium, May 20-22, 1963, Castlewood,  
Pleasanton, California

Impurities such as oxygen, nitrogen, and carbon in either a refractory metal or an alkali metal can have a significant effect on compatibility of the system. In some cases the impurity concentrations sufficient to cause deleterious effects are only several hundred parts per million - levels which might be present in "high purity" metals.

For the case of oxygen in refractory metal-alkali metal systems, this problem is especially important for two reasons: (1) low oxygen concentrations are difficult to obtain and maintain in these metals and (2) at the temperatures required for many applications, oxygen diffusion rates are high. In some systems a deleterious effect of oxygen partitioning is unfavorable modification of the mechanical properties of the refractory metal. Another possible result is the plugging of cooler regions of flowing systems by precipitated alkali metal oxides if sufficient quantities of oxygen have been leached from the refractory metal.

A method to predict the equilibrium distribution of oxygen in refractory metal-alkali metal systems from available thermodynamic and solubility data is presented. Results are compared with experimental data for the niobium-oxygen-potassium and zirconium-oxygen-potassium systems at 815°C.

- 2.225      AGC-SRP-R-397  
CORROSION RATES OF REFRACTORY METALS EXPOSED TO NOZZLE COOLANTS  
C. J. Westcoat. Aerojet-General Corporation, SRP Report No. M  
& F 397, 1 April 1962. Contract No. Nord 17017.

This report summarizes the results of a program to determine the corrosion rates of unalloyed tungsten, tantalum, and molybdenum, and 90% tantalum - 10% tungsten alloy, columbium - 1% zirconium alloy, and C103 columbium alloy exposed to molten lithium, sodium, potassium and magnesium. Rectilinear and Arrhenius plots of all systems are presented up to the boiling point of the molten metals at one atmosphere pressure. The feasibility of cooling nozzles by molten alkali metals has been proven from the viewpoint of corrosion.

- 2.225      NP-11,824  
EVALUATION OF A HIGH STRENGTH NIOBIUM ALLOY, AS-55, FOR ALKALI METAL CONTAINMENT. Feb - May 25, 1962.  
Quarterly Report #2, Contract NAS-3-2140, G.E. Co. FPLD, Cincinnati

Activities are described in a program to determine the properties of Nb-base alloys for alkali metal containment materials in nuclear turbo-electric space power systems. The material being investigated has a nominal composition of Nb, 5% W, 1% Zr, 0.06% C; with a 1% Y addition. The program status is reported concerning the arc melting investigation, ingot conversion evaluation of AS-55 sheet, and corr. testing.

NSA 16:24165

- 2.225      Teitel, R. J., "Boiling Potassium in a Columbium-1% Zirconium Container at 2000°F." Trans. Am Nuclear Soc. 4 (1), 91-2, (June 1961). NSA 15 (16);21103

- 2.225 TID-7626 (Pt 1)  
POTASSIUM CORROSION STUDIES  
E. A. Kovacevich, AiResearch  
(NASA -AEC Liquid Metals Corrosion Meeting, Dec. 1961 at BNL )

Loop and capsule corrosion tests - liquid and vapor potassium at 1000 -2000<sup>0</sup>F. W, Mo, and Cb alloys were included -metals and non-metals corrosion data for potassium.

- 2.225 ENGINEERING PROPERTIES OF POTASSIUM  
First Quarterly Report Covering Period Oct. 1 - Dec. 31, 1960.  
A. W. Lemmon, Jr. (BMI) (NP-10323) Jan 30, 1961

The current program for determining the engineering properties of K, for materials of containment, Nb-1%Zr will be used up to 2100<sup>0</sup>F - stainless steel may be used below 1600<sup>0</sup>F . . .

NSA 15:22734

---

2.226 Other Nonferrous Metals

- 2.226 Oxygen-Exchange Thermodynamics in Liquid Metal Corrosion  
J. R. Weeks, Brookhaven National Laboratory, BNL 728 (C-33) 1962.

Oxygen-exchange may promote embrittlement of the container metal by formation of container-metal oxides which may precipitate internally after oxygen diffusion, as Cb, Ta, Zr by Na + O or K + O.

TO BE EXPANDED IN THE SUPPLEMENT

---

2.227 Nonmetallic Materials

- 2.227 TID-7626 (Pt. 1)  
POTASSIUM CORROSION STUDIES  
E. A. Kovacevich, AiResearch  
(NASA-AEC Liquid Metals Corrosion Meeting, Dec. 1961 at BNL )

Loop and capsule corrosion tests reported with liquid and vapor potassium at 1000 -2000 F. Materials include: Hasteloy X, tungsten, Cb and Mo alloys, and several non-metals (oxides and carbides ) and electrical potting compunds. Results are included in report.

- 2.227 CORROSION RESISTANCE OF VARIOUS CERAMICS AND CERMETS TO LIQUID METALS.  
W. H. Cook USAEC Report ORNL-2391, June 15, 1960.

Ceramics in Na to 1500<sup>0</sup>F and Type 316 stainless steel in K to 1550<sup>0</sup>F.

- 2.227 Action of Potassium on Nongraphitic Carbons by Nicole Platzer  
(Sorbonne, Paris). Compt. rend. 245, 1925-8 (1957).

Graphitizable carbons give insertion compounds such as C<sub>8</sub>K and C<sub>24</sub>K as well as adsorption of K. With nongraphitizable carbons there is only adsorption of the metal. At high temperatures graphitization is limited to the surface of the grains.

CA 52:5189c

2.230 SODIUM SERVICE

2.230 REACTION OF CONSTRUCTION MATERIALS WITH LIQUID METALS

Nikitin, V. I., Teploenergetika, No. 2, 90-2 (1962) In Russian.

The utilization of liquid metals (sodium, potassium, and their alloys, bismuth, and lead) as reactor coolants was analyzed, and the mechanism of their reaction with construction materials was studied. The properties of coolants and construction materials, the temperatures and temperature gradients in the system, the rate of flow, and the presence of admixtures are discussed. The corrosion factors for bismuth and lead depend on their affinity to simple diffusion while for sodium and potassium, corrosion depends mostly on the amount of oxygen present. A table is included of maximum permissible temperatures for various construction materials, showing not more than 0.012 mm corrosion after 1000 hr, in molten sodium and lithium. (R.V.J.)

2.230 Alkali-Metal Corrosion Studies at Rocketdyne, W.T. Chandler  
(NASA-AEC Liquid-Metals Corrosion Meeting, Dec. 1961 at BNL)

Loop and capsule tests utilizing Na, K, and includes data on corrosion of refractory metals. TID-7626 (Part 1)  
(AGN Lib. 2.2786)

2.230 Liquid Metal Corrosion Research in the SNAP Developmental Program  
M. A. Perlow and J. P. Page (AI)  
(NASA-AEC Liquid-Metals Corrosion Meeting, Dec. 1961 at BNL)

The results on corrosion are summarized. TID-7626 (Part 1)  
(AGN Lib. 2-2786)

2.230 Amman, J. H., Sprague, T. S., "The Promise of Liquid Metals,"  
Nuclear Energy 11, 13-16 (Jan 1961).

Research and development work carried out on liquid metal reactor coolant systems is reviewed. Some of the problems of generating steam with sodium and how they were met in specific designs are discussed. The chemical activity of sodium and its radioactivity acquired in passing through the reactor created special problems in design and materials. The Submarine Intermediate Reactor Program, which led to the design and installation of the Seawolf power plant, is described. All the development work and lessons learned in operation of the Atomic Power Development Association and Sodium Reactor Experiments units were incorporated into designs of the single-wall tube type.

2.230 NASA TN-D-769, 1960  
SODIUM LIQUID AND VAPOR PHASE CORROSION STUDIES  
NRL - Washington, D. C., T. A. Kovacina.

Thermal properties of Na, Na corrosion of Cb-1Zr is reported, analysis by radiochemical methods.

2.230 High-Temperature Corrosion by Coolants (BNL)  
D. H. Gurninsky and C. J. Klamut, NASA TN D-769, 1960

Na and Hg corrosion, Zr inhibitors, solubility studies, and a variety of capsule and loop tests.

2.230 Liquid-Metals Corrosion Research (ANL)  
V. J. Rutkauskas, NASA TN-D-769, 1960.

Na corrosion on Experimental Breeder Reactor II program.  
NSA 15:13272

- 2.230 PROGRESS RELATING TO CIVILIAN APPLICATIONS DURING MAY 1960  
BMI-1442 (Rev.)  
R. W. Dayton and C. R. Tipton, Jr. July 12, 1960. 100 p. OTS.

Includes mechanisms of wear and friction of various materials in Na, and new methods for determining low concentration of oxygen in Na.

NSA 14:19311

- 2.230 THE BEHAVIOR OF ALLOYS DURING A CONTACT WITH SODIUM  
Kishkin, S. T. and Benediktova, G. P.  
Issledovanie Splavov Tsvetnykh Metal., Adad, Nauk S.S.S.R., Inst.  
Met. im. A. A. Baikova, No. 2, 1923 (1960). NP-tr-510 (p. 1-7).  
Uncl.

NSA 15:21099

- 2.230 Effect of 1200 F Sodium on Austenitic and Ferritic Steels  
Bi-Monthly Progress Report No. 1 for July and August 1959 on  
Thermal Shock, Nitriding, Stressed Corrosion, Unstressed Corrosion  
Mausteller, J. W. and Werner, R. C.  
MSA Research Corp., Callery, Pa.  
MSAR 59-99, Sept. 16, 1959, 22 p. Contract AT(11-1)-765

Completion of preliminary designs for a thermal shock loop, a corrosion loop, and a nitriding loop is reported. Stresses and unstressed corrosion studies are scheduled to be carried out in the same system. A literature search was started, and various sites were contacted to avoid duplication of effort. It was found that some work has been done at 1200 F sodium temperature with various oxygen concentrations, however, part of the data is not consistent. Test plans include corrosion testing of Croloy and stainless steel samples as well as similar and dissimilar welds of these materials in 1200 F sodium.

NSA 14:2695

- 2.230 SODIUM CORROSION AS A FUNCTION OF TIME  
McKee, John M.  
Nuclear Development Corp. of America, White Plains, N. Y.  
Preprint V-114, presented at NE&SC, April 6-9, 1959, Public Auditorium,  
Cleveland, Ohio  
New York, Engineers Joint Council, 1959, 20 p.

Periodic weight loss measurements were made on tabs suspended in duplicate stainless steel thermal convection loops circulating sodium between 1575 and 1100 F for 5000 hours. Considerable decay in corrosion rate was observed due to the formation of a protective ferritic layer of the tab surfaces.

NSA 13:20275

- 2.230 COMPONENTS OF THE FUSED-SALT AND SODIUM CIRCUITS OF THE AIRCRAFT  
REACTOR EXPERIMENT  
Savage, H. W. et al.  
ORNL-2348, Sept. 18, 1958; 43 p.

The Aircraft Reactor Experiment (ARE) successfully demonstrated the feasibility of generating heat by fission in a fused-fluoride circulating fuel. Most of the heat was removed from the reactor by the fused fluoride at 1580 degrees F. Sodium at 1350 F was used to cool the BeO moderator. With minor exceptions all the components proved to be adequate. The development of compounds and fabrication techniques for this reactor consumed a four-year period, during which time the technology of handling high-temperature fluids was extended to equipment operable above 1500 F. The methods used for determining compatibility of materials under static and dynamic conditions, standards for materials, and techniques for welding, fabrication, and assembly and the design criteria for pumps, seals, valves, heat exchangers, cold traps, expansion tanks, instrumentation, preheating devices, insulation, etc., are described.

NSA 12:16694

- 2.230 CORROSION RESISTANCE OF CERTAIN MATERIALS IN SODIUM AND LITHIUM  
V. Layshenko, V. Zotov, V. Ivanov, and V. Andreyer.  
Second United Nations International Conference on the Peaceful  
Uses of Atomic Energy, April 16, 1958. Paper No. A/CONF  
15/P/2194.
- 2.230 Effects of Sodium and Water Leaks on Experimental SDR Barriers.  
C. Bolta and J. O'Neill. Aug. 15, 1958. 45 p. (NDA-84-9)  
\$7.80(ph), \$3.30(mf) OTS. TID 3544 NSA 12:15501
- 2.230 Resistance of Barrier Materials to Sodium Jet Impingement. Feb. 26,  
1958. 48 p. (NDA-084-4) \$7.80(ph), \$3.30(mf) OTS.  
TID 3544 NSA 12:9147
- 2.230 Corrosion Resistance of Materials in Sodium and Lithium  
V. S. Lyashenko, V. V. Zotov, V. E. Andreav, M. D. Abramovitch and  
V. I. Ivanov. Paper from "Peaceful Uses of Atomic Energy". v. 7.  
Reactor Technology. United Nations, Geneva, Switzerland, 1958,  
p. 111-118.

The corrosion-erosion resistance of carbon steels, Ni-Cr steels, Cr  
steels and Ni and the carburization capacity of some alloys is measured. The  
effect of corrosion on ultimate strength and elongation is shown. 6 ref.

The results of investigation of corrosion of steels in the flow  
of sodium contaminated with oxygen are presented. It was found that  
strength of many steels increases almost in the same degree while their  
relative elongation decreases differently. The erosion resistance of cylindrical  
samples of various steels and nickel when heated in sodium was also  
studied. In addition, the results of investigation of corrosion resistance  
of certain steels and pure metals in lithium under static conditions are  
presented. It was found that carbon steels with 0.06 to 0.7% carbon content  
are unstable due to the carbon transfer from steel to lithium. The ductility  
of carbon steels after their holding for a certain time in lithium has been  
found to decrease sharply. Preferential corrosion of the steels high  
in carbon is observed. It was proved that steels containing chromium,  
tungsten, niobium, and molybdenum resist corrosive interaction with  
lithium more effectively.

NSA 13:6832

- 2.230 AEC tr. 5409  
Resistance to Corrosion of Austenitic and Ferro-Pearlitic Steels  
in a Stream of Liquid Na at Temperatures of 600° and 700° C.  
V. S. Lyashenko, V. V. Zotov; V. A. Ivanov. IAEA Preprint CN 13/50  
17 pp. (In Russian)

Results are given of experimental work on resistance to corrosion of  
various constructional materials in a stream of liquid Na at temperatures  
600°-700°C. Experiments were continued for 6500 hours in dynamic loop condi-  
tions . . . . . After the experiment in Na containing 0.004-0.006 wt % of  
O<sub>2</sub>, the austenitic and the ferro-pearlitic steels both had a relatively high  
combination of mech. qualities. However, some ferro-pearlitic steels tended  
to have a partial carbon loss when used in conjunction with austenitic steels.  
The nature of the interaction of the steels with Na and the changes occurring  
in the absence of a medium are analyzed. Results are also given of experi-  
ments with various steels in a stream of impure Na containing 0.02-0.04 wt %  
O<sub>2</sub> and the results of using Calcium as an inhibitor to the Na. The data  
indicate that, in isothermal conditions, the addition of 0.2% Ca to the Na  
significantly lowered corrosion attack on austenitic stainless steel.

- 2.230 IGR-TN/C-857 Uncl.  
COMPATIBILITY OF REACTOR MATERIALS IN FLOWING SODIUM  
United Kingdom Atomic Energy Authority. Industrial Group.  
Culcheth Laboratories, Culcheth, Lancs, England.  
M. Davis and A. Draycott, 1958. 52p. (ACR 15:202)



- 2.230 THE MECHANISM OF CARBON TRANSFERS IN LIQUID SODIUM  
V. S. Lyashenko and B. A. Nevzovov IAEA Preprint CN 13/41, 36p.  
(In Russian)

Experiments were carried out to investigate transfer of carbon from cast iron, carbon steel, by alloy perlite steel, and chrome steel to austenitic steel and high-nickel alloys in liquid Na with varying  $O_2$  content at temp. up to  $650^\circ C$ . The relationship between decarburization and carbonization of steels and their chemical comp. and content of carbide-forming elements and carbides is shown. Certain kinetic relationships between carbon transfer and Na- $O_2$  content, the temp. and the duration of process were investigated. Experiments are described showing details of the various processes observed in transfer of C to liquid and gaseous Na and also determining the part played by ionic  $O_2$  in the formation of CO, the carbon carrier. The probable mechanism of carbon transfer in liquid Na is discussed, this mechanism consisting of 2 stages. 1<sup>st</sup> stage covers formation of CO molecules on the surface of certain materials as the result of reaction between  $O_2$  and C, and also involve diffusion of CO thru the volume of reaction.

NSA 16:22160

- 2.230 Compatibility of Reactor Materials in Flowing Sodium  
Davis, M. and Draycott, A.  
United Kingdom Atomic Energy Authority Culcheth, Lance,  
England. Atomic Energy Commission, Australia  
A/CONF. 15/P/25 36p.  
NSA 13:6764 page 901

The validity of various types of compatibility tests is briefly discussed, particularly the severe limitations of static experiments. Differences expected between sodium and NaK are noted. A typical corrosion test rig is described and its application to radioactive mass-transfer measurements discussed. The types of specimens used, the measurements made before and after tests, the assessment of the results, and their correlation with reactor circuits are detailed. The variables studied include the temperature of the specimen, the velocity of the liquid metal over the specimen, the oxide level in the liquid metal and the initial state of the specimen. The materials investigated include stainless steel, various ferritic steels, zirconium, niobium, vanadium, uranium, and fission products, thorium, and beryllium. Niobium and vanadium were studied in greatest detail.

- 2.230 SOLID METAL-LIQUID METAL REACTIONS IN BISMUTH AND SODIUM.  
John R. Weeks and David H. Gurinsky (Brookhaven National Lab.,  
Upton, N. Y.). Liquid Metals and Solidification, Seminar 39th  
Natl. Metal Congr., Chicago 1957, 190-63 (Pub. 1958).

A 44 reference review of the current status of the theory of solid-liquid metal interactions (or corrosion) and its possible applications to the construction of a liquid U-Bi fueled nuclear reactor is given.

CA53-2991f

- 2.230 COMPONENTS: PIPING SYSTEM COMPONENTS  
F. A. Smith (ANL) p. 205-14 of Proceedings of the 1957 Fast  
Reactor Information Meeting held at Chicago, Ill., Nov. 20-21, 1957.

. . . no serious technical or economical limitation for the reliable operation of Na piping components at temperatures up to  $1000^\circ F$ .

NSA 13:16598

- 2.230 Activity Transport in Sodium-Cooled Systems  
Fred Haag; KAPL, Nucleonics (Feb 1957)

Radioactivity induced in stainless steel and transported in the coolant stream can limit access to parts of a reactor system. Transfer rates are particularly sensitive to temperature and oxides. Barium is an effective inhibitor - 1 wt% substantially reduces transport.

- 2.230 AD 256511  
DESIGN, FABRICATION AND PERFORMANCE OF THE DUPLEX HEAT TRANSFER TUBE  
Mehring, R. J.  
(Knolls Atomic Power Lab., Schenectady, N. Y.) KAPL-1797, 60 p.  
(Sept. 28, 1956. Decl. Apr. 4, 1958)

The heat transfer characteristics and stress levels in duplex tube for heat exchangers are interdependent. This summary assembles into a single report the various studies of the heat transfer characteristics and stress analyses that have been made. The heat transfer characteristics discussed are those for boiling water, liquid metal, and metal-in-metal contact. Analyses have also been made of the fabrication and operating stresses. As a result, recommendations have been made regarding material properties, tolerances, and surface conditions of the tubular components, fabricating procedures, and operating precautions. Where areas of uncertainty still exist, tests have been recommended. This information is significant to the SIG Test Steam Generator Program, since this steam generator is to have duplex heat exchanger tubes.

- 2.230 Corrosion by Liquid Metals. Epstein, L. F. Metaux. (Corrosion-Inds.) 32, 490-1 (1957). Corrosion of Uranium in Liquid Sodium. Mogard, H. Ibid. 491-2. Corrosion Problems Posed by Bismuth-Uranium Fuels. Weeks, J. R. et al. Ibid. 492-3. Solubility of Materials of Construction in Sodium. Baus, R. A. et al. Ibid. 493-4. Behavior of Unoxidizable Alloy IX18H9T in Contact with Lead, Bismuth, and their Eutectic Mixture in the Liquid State at a Temperature of 500 to 600°. Tsouproun, L. I. et al. Ibid. 494-5. Corrosion of Zirconium and Its Mixtures with Water at Elevated Temperatures. Thomas, D. E. Ibid. 495-7. Principles of the Technology of the Sodium-Graphite Pile. Siegel, Sidney et al. Ibid. 497-8.

The above are papers presented at a symposium on special aspects of corrosion in atomic energy installations. CA 52:8910

- 2.230 The Corrosion Testing of Various Materials in Sodium. Part I. Dudek, R. F., Part II. Ferguson, K. Mildred, April 26, 1957. 39 p.  
Babcock and Wilcox Co. Research Center, Alliance, Ohio BW-7020

These tests were conducted to determine the corrosion resistance of various materials to liquid sodium at a temperature of 1100 F. Four separate tests were conducted using a modified enclosed-rotor motor pump corrosion apparatus with sodium at 1100 F and with the specimens at an absolute velocity of 55 ft/sec and static. The materials tested were a group of 300 and 400 series stainless alloys, low Croloys, carbon steel nickel alloys, zirconium, and Lukens-clad stainless steels. Oxygen was controlled by the use of a diffusion-type cold trap for three of the four tests. A flow-through cold trap was used for the fourth test. The measurement of the oxygen content was made both chemically and by the use of plugging indicator. After test, the specimens were subjected to metallographic investigation.

NSA 12:7808

- 2.230 TID-7525  
Atomics International Div., North American Aviation, Inc., Canoga Park, Calif. Proceedings of the SRE-OMRE Forum Held at Los Angeles, California, Nov. 8 & 9, 1956. January 15, 1957. 313p. NAA-SR-1804

Papers on the Sodium Reactor Experiment include discussions of the design, physical progress, operations, component development and fabrication, fuel materials, and zirconium problems. Papers on the Organic Moderated Reactor Experiment include discussions of the design, construction progress, research and economics.

Nuclear Notes for Industry dated 4/26/57

- 2.230 PWAC-572 (Secret)  
Pratt and Whitney Aircraft Division, United Aircraft Corporation  
Middletown, Connecticut. NUCLEAR PROPULSION PROGRAM ENGINEERING  
PROGRESS REPORT NO. 24 FOR APRIL 1, 1957 - JUNE 30, 1957. 144p.  
...stainless steel in liquid metals; stainless steel, Ti and Nb  
corrosion... by liquid Na and Li ....

ACR 13:2441

- 2.230 ORNL-2685 Unc. Oak Ridge National Laboratory, Tennessee  
Papers presented at ANP Materials Meeting, November 16-18, 1954  
(Wright Air Development Center, Dayton, Ohio) March, 1959. 168 p.  
... corrosion of stainless steel and Inconel by Li, Na, and Rb  
.... corrosion characteristics of a number of metals and alloys in  
liquid lead...

NSA 14:24489

- 2.230 Corrosion Resistance of Metals and Alloys to Sodium and Lithium  
E. E. Hoffman and W. D. Manly (Oak Ridge National Lab., Oak Ridge,  
Tenn.) U. S. Atomic Energy Commission ORNL-2271, 11 pp. (1957)

Methods and equipment are given for dynamic testing of metals and alloys for corrosion by Na and Li as heat-transfer liquids. The Na contained < 25 ppm O. Lowering the concentration of O decreases the rate of mass transfer but does not eliminate it in a Ni-base alloy such as Inconel. Bar graphs give a temperature below which systems might be operated with Na or Li for 1000 hours with 2 0.005 in. attack on Fe, low-alloy steel, ferritic stainless steel, austenitic stainless steel, Ni, Inconel, Co, Stellite, Cu, Cu-base alloys, refractory metals (Mo, Nb, Ta, Zr, Ti, W, and V) and precious metals (Ag, Au, and Pt) both for static and for dynamic systems.  $Li_3N$  is the most harmful contaminant in Li. The austenitic (300 series) stainless steels are the most satisfactory structural materials for Na below 1500°F. No satisfactory material has been found to handle Li in dynamic systems above 1200°F. Below 1000°F the stainless steels give good resistance.

- 2.230 Compatibility Tests of Various Materials in Molten Sodium  
Carlander, R. and Hoffman, E. E.  
Oak Ridge National Laboratory, Tennessee  
CF-57-3-126. 25 March 1957, Decl. 9 October 1959, 10p.  
NSA 14:2692

Compatibility tests of materials in contact in sodium under 500 psi pressure were conducted for 716 hr at 1500 F. Of the diffusion couples studied, the Inconel-beryllium system showed the largest amount of alloying. The reaction between molybdenum and beryllium resulted in the formation of two compounds, both of which were severely cracked in several areas. The molybdenum-Inor-8 and the Inor-8-type 316 stainless steel interfaces showed little alloying. A compatibility test system was prepared by placing 1/4 x 1/2 x 1 in. specimens of Inconel, beryllium, molybdenum, Inor-8, and type 316 stainless steel together in sodium.

- 2.230 AD-T-256511 TRANSFER OF CARBON BETWEEN DISSIMILAR METALS IN CONTACT WITH MOLTEN SODIUM TESTS CONDITIONS: 1000°C - 400 HOURS  
Carlander, R. and E. E. Hoffman  
(ORNL, Oak Ridge, Tenn.) CF-56-4-73, 8 p. (Apr. 2, 1956)

The extent to which AISI-C 1043 steel is decarburized in certain materials when in contact with molten sodium has been determined at 1000°C for 400 hours. The extent of decarburization of a steel specimen was greater when an Armco iron container was used than when a type 304 elec. stainless steel container was used. In addition, sufficient nickel mass transferred to the surface of the AISI-C 1043 steel in the stainless steel test to cause a phase transformation to a depth of 2 to 4 mils. The extent of carburization of the AISI-C steel was greater in the 400 hour test than in a previous 100 hour test under similar test conditions. The amount of nickel mass transferred to the surface of the steel specimen was greater in the 400 hour test than in the 100 hour test under similar test conditions.

The amount of nickel mass transferred to the surface of the steel specimen was greater in the 400 hour test than in the 100 hour test and furthermore, carburization of the vapor zone of the stainless steel capsule occurred while it did not in the previous 100 hour test. Further tests are to be performed in which the extent of decarburization will be studied when an inert container material (tantalum) and sodium low in oxygen (distilled) will be used.

- 2.230 See Also: 2.330, 3.430, and 4.300.

- 2.230 SODIUM GRAPHITE REACTOR QUARTERLY PROGRESS REPORT [FOR] JULY-SEPTEMBER 1956. L. E. Glasgow, ed. Jan. 15, 1957. 61p. (NAA-SR-1760).

Studies were made of various alternate core configurations for the SRE. Determinations were made of SRE power and temperature coefficients of reactivity. Lattice code computations given an over-all temperature coefficient of reactivity of  $+9 \times 10^{-5}/^{\circ}\text{C}$  at  $200^{\circ}\text{C}$ . Schematic diagrams are given of the dynamic cold-trapped Na loop (NaZrI) and of the hot-trapped loop (NaZrII). The weight gain for samples of technical reactor grade Zr exposed to cold-trapped Na was further investigated. The effects of surface oxide, dissolved  $\text{H}_2$ , and grain size on the fatigue life of Zr test specimens are shown graphically. Tensile tests of SRE Zr exposed to Na were performed at 500 and  $985^{\circ}\text{F}$  and results are tabulated. The dimensional stability of moderator can Zr under thermal cycling was rechecked. An analog analysis was made of the SRE main airblast heat exchanger. Figures are given to show some of the representative severe transients that were run on the analog computer. Progress on reactor construction is briefly described. Tests to determine the ability of Stellite No. 3 and Stellite No. 6 to withstand reactor operating temperatures were continued. Tests on the safety rod prototype are also summarized. Calculations were made to determine the  $\gamma$ -ray dose rates at SRE instrument tubes. A summary of data for Na centrifugal pumps is given. Pump washing experiments were conducted to ascertain the problems involved in cleaning centrifugal pumps after service in a Na system.

- 2.230 SODIUM GRAPHITE REACTOR QUARTERLY PROGRESS REPORT [FOR] OCTOBER-DECEMBER 1955. SECTION A. A. B. Martin, ed. SECTION B. J. C. Cochran, ed. Apr. 15, 1956. Decl. Apr. 8, 1957. 100p. (NAA-SR-1582)

An analysis was made of the nuclear parameters for sodium graphite reactor lattices. These parameters include thermal utilization, macroscopic cross sections, thermal diffusion length, and neutron absorption. Results of all calculations are given in graphical form. The percent elongation of graphite due to the presence of Na is shown for various temperatures. The behavior of Zr in liquid Na was studied, and weight gains in Zr are summarized. Analog computer studies were continued, and data are included on the temperature effects of the response time of coolant channel Na outlet temperature thermocouples, the effects of continuous rod motion and pump speed changes on the outlet Na temperature and power, and the outlet temperature as a function of scram time. Tests were completed on Freeze Seal No. 2 for the 6-in. oval port Wedgeplug test valve at 450, 850, and  $1250^{\circ}\text{F}$ .

- 2.230 NAA-SR-258  
North American Aviation, Inc., Downey, California  
Compatibility of Sodium, Graphite and Stainless Steel by  
Coultas, T. A. and R. Cygan July 8, 1953. Decl. March 5, 1957.  
Contract AT-11-1-GEN-8 30 p.

Experiments have been performed to determine the compatibility of graphite and molten Na under various conditions. Effects such as corrosion, thermal shock, dimensional changes and penetration of Na into the graphite pores were investigated. Significant corrosive attack on the graphite was noted only in the presence of carburization of the container material. Stainless steel showed no appreciable carburization below  $550^{\circ}\text{C}$ , but carburization was found at temperatures of  $600^{\circ}\text{C}$  and higher. Carburization of Zr was observed only at  $750^{\circ}\text{C}$  and higher. Graphite was found to be wet by liquid Na above  $150^{\circ}\text{C}$  and to absorb the Na into its pores above the level of the bulk liquid by capillary action. Experiments with previously irradiated graphite indicated no significant differences in behavior from that of the unirradiated material.

NSA 11:9725

- 2.230 Compatibility of Reactor Materials in Flowing Sodium.  
M. Davis and A. Draycott. Paper from "Peaceful Uses of Atomic Energy." v. 7. Reactor Technology. United Nations, Geneva, Switzerland, 1958, p. 94-110.

Measurement of the corrosion rate of  $\text{Cb}$ ,  $\text{C}$ , 18-8 stainless steel, U, fission products and Zr in flowing Na as a function of flow velocity, temperature and use of deoxidants. 18 ref.

- 2.230 THE CORROSION TESTING OF VARIOUS MATERIALS IN SODIUM, PART I.  
R. F. Dudek. PART II. K. Mildred Ferguson. Apr. 26, 1957. 39p.  
(BW-7020)

Tests were conducted to determine the corrosion resistance of various materials to liquid Na at a temperature of 1100°F. Four separate tests were conducted using a modified enclosed-rotor pump corrosion apparatus with Na at 1100°F and with the specimens at an absolute velocity of 55 ft/sec and static. The materials tested were a group of 300 and 400 series stainless alloys, low Croloys, carbon steel, Ni alloys, Zr, and Lukens clad stainless steels.

- 2.230 BW-3792  
W. Markert, Jr., Babcock and Wilcox Co., Research Center, Alliance, Ohio. The Corrosion Testing of Various Materials in Sodium  
August 4, 1954, 31p.

These tests were conducted to determine the corrosion resistance of various structural materials to liquid sodium at a temperature of 1100 F and to determine if the materials are satisfactory for use in a reactor power plant. Three separate tests were conducted using a modified enclosed rotor pump corrosion apparatus with sodium at 1100 F and with the specimens at an absolute velocity of 55 ft/sec and static. The materials investigated were a group of 300 series stainless steels, Croloys, nickel alloys, Zircaloy 2, carbon steel, Globeiron, and modified Globeiron. The Globeiron materials were essentially extra low carbon iron to which various alloy materials had been added in two cases.

NSA 12:7806

- 2.230 KAPL-M-LFE-16  
Objective Study of Barrier Materials for Sodium-Water Systems  
Epstein, Leo F. (KAPL, Schenectady, N. Y. ) USAEC 1955

By starting with 1st principles, various materials are eliminated for failure to meet the requirements for barrier materials for the Na-H<sub>2</sub>O reactor system. The term third fluid has been discarded because solids should also be considered. The only feasible materials are a solid barrier (with gas, e.g., He as the leak indicator), and metals which are liquid at room temperature, Cu and Ag are suggested as good possibilities. Among the liquid metals, only NaK (23:77, melting point 12°F) and Hg appear to be possibilities, with Hg in almost unequivocal favor except for its toxicity hazard, which it is believed can be controlled. Operating experience with Hg over a year has been satisfactory, while that with NaK suffered from difficulties with filling and cleaning, and accelerated corrosion. The expected high melting compound with Hg when Na leaks has failed to form.

CA 51:4158

- 2.230 ANL - 5260 (Del. 2)  
REACTOR ENGINEERING DIVISION QUARTERLY REPORT (FOR) DECEMBER 1,  
1953 THROUGH MARCH 30, 1954. Apr. 15, 1954. Decl. with deletions  
Apr. 8, 1957. 185p.

Boiling Experimental Reactor (BER). An H<sub>2</sub>O-type reactor has been selected for an initial pilot boiling reactor. Information given here pertains to the D<sub>2</sub>O design developed during the course of study. Plate-type and co-extruded tubular fuel element assemblies were considered for this reactor. Several cross section drawings of the proposed design are given. EBR-II. Several tank designs are proposed whereby the primary system, submerged in a Na-filled, double-walled tank, may be connected to the reactor vessel. Moderator, Reflector and Structural Materials. Zn(C<sub>2</sub>H<sub>3</sub>O<sub>2</sub>)<sub>2</sub> and ZnO were found to be effective corrosion inhibitors of 347 stainless steel and 2-S Al. An apparatus was constructed for thermal conductivity determinations of reactor materials up to 1000°F. The embrittling effects of irradiation, H<sub>2</sub>, and temperature on the impact properties of materials were studied. The specimens tested included a variety of stainless steels, Ni-A, Ni alloys, Co alloys, and Zr.

- 2.230 NP-5449  
Report No. 7, March 1, 1954 Thru May 7, 1954 to the Detroit  
Edison Company. J. R. Taylor, S. J. Rodgers, and H. J. Williams  
July 25, 1954. 37 p.

A 30-day test on Zr tubing produced a metallic deposit on a large portion of the outer or NaK contacting surface. The deposit was found to be very magnetic, and a chemical analysis showed that it was 75% Fe. The deposit formation was believed to have been caused by a form of mass-transfer due to the coexistence of a temperature differential and metals (type-316 stainless steel) having temperature-dependent solubilities in NaK. Weight and dimensional determinations made on the specimen tube before and after exposure showed no appreciable gain or loss of weight nor change in wall thickness. A metallurgical examination of the exposed Zr specimen the presence of black needle-like spider-web constituent which appeared to be at the grain boundaries penetrating to as much as half the thickness of the tube from the Na contacting side. This constituent was thought to be Zr hydrides. An examination by polarized light showed that recrystallization took place in all sections of the tube. A change in grain structure on the Na contacting surface was also evident with polarized light. An examination of the type-347 stainless steel IHX tube showed no erosion or corrosion and the tube structure was normal. An average concentration of 1.8 ppm of Zr at the sampling temperature was found in metal samples taken from the Na stream during the test. A total of less than 1 mg of Zr was found in Na and NaK cold traps analyzed at the conclusion of the tests, indicating that the amount of tube material lost to the liquid metals during the 30-day test was negligible.

- 2.230 Some Factors Influencing the Compatibility of Metals with Sodium, Potassium, and Uranium  
Mc Intosh, A. B., Broadley, J. S. and Bagley, K. Q.  
Great Britain Culcheth Labs., Culcheth, Lancashire, England  
RDB(C)/TN-31 April 29, 1953, 38p. (FRDC/P-27)  
NSA 13:20183

The various factors which may influence the compatibilities of metals with sodium, potassium, and uranium are considered. Where possible, these have been assessed using data which can be calculated or are already available in the literature. By studying the relation between the position of metals in the periodic classification and their compatibilities, it is shown that the most likely constructional metals for a fast reactor fuel element container are to be found in Groups IV, V, and VI.

- 2.230 North American Aviation, Inc.  
THE CORROSION OF REFRACTORY MATERIALS IN SODIUM, by R. L. Loftness,  
W. C. Ruebsamen, and T. A. Coultas. Issued Nov. 20, 1951. Decl.  
with deletions Dec. 1, 1952. 41p. (AECD-3472; NAA-SR-126)

The corrosion of refractory materials in liquid sodium and sodium vapor at 900°C for periods of time up to 1 month was studied under static conditions. Vacuum-distilled sodium was used in all but a few instances. Changes in weight, appearance, and metallographic structure were observed, and post-run chemical analyses of the sodium were made. In general the rates of corrosion were higher in liquid sodium than in sodium vapor. The presence of excessive oxygen in the sodium increased the corrosion rates. In order of decreasing resistance to corrosion by sodium at 900°C the materials are: Molybdenum, tungsten, Haynes Stellite-25 (Co, Cr, W, Ni alloy), type 347 stainless steel, Kennametal-138A (TiC + Co), tantalum, and titanium. Graphite, copper, platinum, spinel, alumina, magnesia, and zirconia showed poor resistance. Silicon carbide, molybdenum silicide, and thoria showed good resistance to corrosion. Synthetic sapphire and single-crystal magnesia had good resistance. Experimental procedures and equipment are described. Analytical methods for the presence of the following substances in sodium are described: oxygen, potassium, calcium, magnesium, silicon, aluminum, nickel, niobium, chromium, iron, molybdenum, tantalum, titanium, tungsten, zirconium, carbon, and sodium carbide (evidenced by acetylene formation). (auth)

NSA Vol. 7 - 183

- 2.230 ORNL-1688  
Oak Ridge National Lab.  
SODIUM PLUMBING. A REVIEW OF THE UNCLASSIFIED RESEARCH AND TECHNOLOGY INVOLVING SODIUM AT THE OAK RIDGE NATIONAL LABORATORY. William B. Cottrell and Leland A. Mann. Aug. 14, 1953. 82p. Contract W-7405-eng-26.

The research data and the development experience relevant to sodium obtained during the period 1950 to 1953 at the Oak Ridge National Lab. are summarized. Methods for testing the corrosion resistance of structural metals in sodium and the results of such tests are presented. The developmental work that has been done on the various components of sodium systems is described, and the relative merits of commercially available components are discussed. Cleaning, assembly, leak testing, and operating techniques and precautions are given. (auth)

NSA Vol. 8 2824

- 2.230 ORNL-1647  
Oak Ridge National Lab., Tenn.  
Static Liquid-Metal Corrosion. Interim Report (covering) the Period July 1949- September 1952. by Brasunas, Anton deS and W. D. Manly, ed. May 11, 1954. Decl. March 12, 1957. 99p.  
Contract W-7405-eng-26.

Static corrosion tests have been made in molten sodium, lithium, lead, bismuth, and several alloys containing uranium. Temperatures have been varied, but the bulk of the data is concerned with tests made at 1000°C (1832°F). Sodium was found to be the least corrosive in static and dynamic tests, and almost all alloys tested have shown good corrosion resistance. Lithium, on the other hand, attacked many alloys quite severely, especially nickel-containing alloys. Thermal gradient dynamic tests have also shown lithium to be much less attractive than sodium because of the susceptibility to mass transfer. Lead and bismuth were quite similar to lithium in many respects, both in static and dynamic corrosion tests, and are compatible with very few metals at 1000°C (1832°F).

NSA 11:9747

- 2.230 METALLURGY DIVISION QUARTERLY PROGRESS REPORT FOR PERIOD ENDING JULY 31, 1951.  
E. C. Miller and W. H. Bridges, eds.  
Feb. 6, 1952. Decl. Oct. 9, 1959. 92p. Contract W-7405-eng-26. OTS.  
Oak Ridge National Lab., Tenn. ORNL-1108

The corrosion testing of various metals and alloys in liquid sodium, lead, and lithium and in molten fluorides and hydroxides was continued. The interaction of sodium with 316 stainless steel appears negligible during static testing. The testing of the molten media in thermal convection loops continues to be plagued by failures other than corrosion. The study of thermocouple stability in vacuum has shown that chromel-alumel couples give consistent checks with control and reference temperatures, whereas iron-constantan and platinum-10% rhodium couples gave erratic results. Some preliminary results were obtained on uranium, thorium, 316 stainless steel Inconel, and columbium. The evaluation of welded tube-to-header joints of Inconel received considerable attention. Tests in tension show that the joint is of the same order of magnitude as the original material, the failure occurring in the zone adjacent to the weld. A rotating tubular beam fatigue test apparatus was developed, and preliminary tests show that joints with complete penetration have better fatigue life than joints with 70% penetration. The establishment of a ceramics laboratory proceeded satisfactorily. Basic research, engineering development, and service work will be done. In research on the fundamentals of liquid metal--solid metal interaction, the immersion of copper in liquid bismuth resulted in the deposition of copper crystals removed from the specimen. This might be the result of one or more mechanisms: thermal gradients, thermal cycling, or free energy changes. A program to investigate the alloys of the transition elements in order to reconcile the theories of Mott and Jones, and Pauling concerning these elements was initiated.

NSA V. 14 #3 - 2672

- 2.231 Compatibility of Reactor Materials in Flowing Na. M. Davis & A. Draycott, Proc. U.N. International Conference Peaceful Uses Atomic Energy ; 2nd Geneva (1958) 794-110. v7

The materials fall into three classes in regard to their compatibility with Na or Na-K (1) those with oxide less stable than  $\text{Na}_2\text{O}$  or of comparable stability (steels and nickel) (2) those possessing oxides more stable than  $\text{Na}_2\text{O}$  and having con. products adherent to the parent metal (Zr) and (3) those with more stable oxides that are not adherent (Nb, V, U, Ti, Be)  $\text{O}_2$  levels much lower than 20 ppm are required for compatibility with all the materials except the steel and Ni. Radioactive mass transfer was studied and a unique corrosion meter for detecting  $\text{O}_2$  level is described. CA55.23094-a

- 2.231 Corrosion and Decarburization of the Ferritic Chromium-Molybdenum Steels in Sodium Coolant Systems, Hayes, W. C. and Shepard, O. C. North American Aviation, Inc. Atomic International, Canoga Park, California Contract AT(11-1)-Gen-8 December, 1958. 32p. NAA-SR-2973

NSA 13:3821

- 2.231 ORNL-2271 Uncl. Oak Ridge National Laboratory, Tennessee. Corrosion Resistance of Metals and Alloys to Sodium and Lithium E. E. Hoffman and W. D. Manly. April, 1957. 11 p. RL

- 2.231 Use of Zirconium in Liquid Sodium Systems Bowman, F. E. and D. D. Cubicciotti A.I.Ch.E. J. 2, 173-6 (1956).

The attractive nuclear properties of zirconium make it a highly desirable core material for sodium-cooled reactors. The elevated temperature strength, while low, is sufficient for certain applications. Development of higher strength alloys is under way. Sodium in itself is completely compatible with zirconium; however, the nonmetallic contaminants, namely oxygen, hydrogen and nitrogen, can effect serious damage. The primary problem in the use of zirconium in a sodium system, then, lies in controlling these impurities in the sodium.

TO BE EXPANDED IN THE SUPPLEMENT

## 2.232 Ferritic and Martensitic Steels

- 2.232 EFFECT OF 1200°F SODIUM ON AUSTENITIC AND FERRITIC STEELS. PHYSICAL PROPERTIES OF MATERIALS Progress report 25 Sept 1962 (MSAR-62-126)

Results of stress-rupture tests, creep tests, and fatigue tests of Cr-Mo steel in Na and air. (More on abstract)

NSA 17:3425

- 2.232 "Corrosion of Iron and Steel in Liquid Na," C. Tyzack, Iron and Steel Inst. (London) Spec. Rept. No. 69 70-206 (1961).

A review with nine references.



- 2.232 NAA-SR-6162, Nitriding of Type 304 Stainless Steel in a Sodium-Nitrogen System, Gill, J. T., Bokros, J. C., (May 30, 1961).

Type 304 stainless steel is nitrided in 1000°F sodium system covered with nitrogen gas. Observations were made using a flowing-sodium loop. The degree of nitriding is heaviest at the interface between the sodium and nitrogen. The nitriding process strengthens the type 304 stainless steel at elevated temperatures and produces a marked decrease in its ductility. The stress-rupture life is greatly decreased at 1000°F because of nitriding. At a deflection of 0.76 in. producing a stress of 36,000 psi, the flexural fatigue life is significantly increased by nitriding.

- 2.232 NAA SR-5350  
AEC CLASSIFIED PROGRAMS FOR FISCAL YEAR 1960  
USAEC Report NAA-SR-5350. AI. Aug 1960.

Modifications to Croloy steels to improve corrosion resistance in Na to 1050°F.

- 2.232 Some Observations on the Interaction of Liquid Sodium with Cast Irons and Plain Carbon Steels, Smith, A. A. and Smith, G. C.  
Univ. of Cambridge, Eng. J. Iron Steel Inst. (London) 196, 29-42 (1960)

The decarburizing action and allied effects of molten sodium on ferrous materials were investigated, and it is shown that decarburization by sodium depends on the presence of a sink in which the carbon removed from the specimen may be deposited. Cast irons are rapidly penetrated by the sodium, and modification of the microstructure in the interior of the specimen may result, even where there is no removal of carbon from the iron. The formation of surface layers and crystals was noted on steels immersed in a sodium and was ascribed to the transport of material from the container in which the test was carried out. Some measurements were made on the rate of decarburization of plain carbon steels by sodium over the temperature range 600 to 850 C, and the results were correlated with the iron-carbon phase diagram and the diffusion rates of carbon in ferrite and austenitic.

NSA 15:4250

- 2.232 NUCLEAR ENGINEERING DEPARTMENT PROGRESS REPORT FOR MAY 1 - AUGUST 31, 1959  
USAEC Report BNL-583, April 1960

LMFRE Project, B1 in various ferritic steels, ( 9 Cr-1Mo.)

- 2.232 SODIUM AND SODIUM-POTASSIUM ALLOYS AS HEAT TRANSFER MEDIA FOR STEAM REHEAT AND TECHNOLOGICAL PROCESSES  
P. L. Kirillov. Teploenergetika, No. 10, 40-2 (1960)

Na and NaK may be considered as heat transfer media. Their physical properties are given. Published data covers the range of 0-700°C and the data for higher temperatures are obtained by extrapolation. Reaction between Na and H<sub>2</sub>O would have to be prevented, but that between Na and steam is not so dangerous. Oxidation of the Na must be prevented for two reasons: the oxides are corrosive and they may form solid deposits in the tube. Before filling the system, it would have to be heated to a temperature higher than the melting point of Na which is 97°C. This would not be required if the eutectic alloys of Na and K were used, the melting point being below 20°C. A possible reheat circuit using Na metal or NaK is illustrated schematically and the main characteristics are given. Various items of secondary equipment are described, including, for example, measurement of Na<sub>2</sub>O. If the Na or NaK leaked into the furnace it would quickly burn, forming oxides and carbonates most of which would be removed with the flue gases. The Na does not come in contact with the water. The pressure of the steam is much higher than that of the sodium and if any leak occurred, it would be of steam into the Na. Various kinds of protective measures that would be required are mentioned. The use of electromagnetic pumps for metallic Na is recommended. Ordinary ferrite steels can be used in contact with Na up to 450° to 500°C; and austenitic steel up to 800°C, provided that the oxygen content does not exceed 0.005% by weight. (OTS)

NSA 15:24953

- 2.232 BAW-1170  
 2.232 BABCOCK AND WILCOX CO. LIQUID METAL FUEL REACTOR EXPERIMENT  
QUARTERLY TECHNICAL REPORT FOR APRIL-JUNE 1959  
 USAEC Report BAW-1170, 1959
- 2.232 BAW-1019 (Suppl. 1)  
 2.232 LIQUID METAL FUEL REACTOR EXPERIMENT (PHASE 1C) SUPPLEMENT TO  
LMFRE REFERENCE DESIGN REPORT, DEC. 1957  
 36 p. BAW-1019 (Suppl. 1)

NSA 13: 13087

- 2.232 MSAR-59-99  
EFFECT OF 1200°F SODIUM ON AUSTENITIC AND FERRITIC STEELS  
 J. W. Mausteller and R. C. Werner. Bi-monthly Progress Report No. 1  
 for July and August 1959 (on) THERMAL SHOCK, NITRIDING, STRESSED  
 CORROSION, UNSTRESSED CORROSION. Sept. 16, 1959. 22p. Contract  
 AT(11-1)-765, MSA Research Corp., Callery, Penn.

Completion of preliminary designs for a thermal shock loop, a corrosion loop, and a nitriding loop is reported. Stressed and unstressed corrosion studies are scheduled to be carried out in the same system. A literature search was started, and various sites were contacted to avoid duplication of effort. It was found that some work has been done at 1200°F sodium temperature with various oxygen concentrations, however, part of the data is contradictory. Test plans include corrosion testing of Croloy and stainless steel samples as well as similar and dissimilar welds of these materials in 1200°F sodium. (J.R.D.)

NSA 14-3-2695

- 2.232 AD254791 The Role of O<sub>2</sub> in the Brittle Behavior of Metals by  
 E. S. Fankins, Prog Rep 4 A.M.L., Naval Air Mat'l Center, Phila. Pa.  
 TED No. NAM RS 7045

Equilibria in the following reaction was investigated in the temp range of 1460-1700°C.  $H_2 + O$  (in liq metal)  $\rightarrow H_2O$ . The max solubility of the Oxy in the Liq Metal was determined. These results are discussed as well as the eq. for max % of O<sub>2</sub> in the different metals. A summary of visits to various labs in Europe is also reported.

- 2.232 CF-59-2-46 (Secret) Oak Ridge National Laboratory, Tennessee  
Summary Statement and Bibliography of Liquid-Metal Technology  
Developed at the Oak Ridge National Laboratory. February, 1959  
 Includes attachments 1, 2, and 3. 43p.  
 ... alloy steels in contact with sodium at 1100 to 1300°F

ACR 17:73

- 2.232 NRL-Memo-581  
 Naval Research Lab., Washington, D. C.  
Evaluation of Croloy Steel for Sodium Use by Brown, B. F. March 23,  
 1956. 14p. Project No. NS 200-021

The resistance of Croloy 2 1/4 to corrosion by Na was studied in thermal convection harps. The results of these tests indicate that there is no mass transfer of Croloy 2 1/4 at 500°C (923°F) maximum temperature with a delta T of 175°C (315°F), no decarburization of Croloy 2 1/4, no carburization of Type 347 stainless steel in the presence of Croloy, and no detachable difference in effect of O concentration in Na at 0.003 wt. % and 0.014 wt. %.

NSA 11:5311

- 2.232 NAA-SR-2973  
Corrosion and Decarburization of the Ferritic Chromium-Molybdenum  
Steels in Sodium Coolant Systems. W.C.Hayes and O.C. Shepard

2.232

NP-6649 UNCLASSIFIED

Cambridge Univ., England

The Physical and Chemical Change in Metals Associated with a Liquid Metal Environment. The Interaction of Sodium and Ferrous Materials at High Temperatures (thesis).

Smith, A. A.

Aug. 1955. 224 p. Contract 13/5/165/226. (AERE-X/PR-1087 (Aug. 1955)).

The effects of static Na on cast irons and steels at temperatures up to 1000°C in vacuum were studied. The results and conclusions are summarized. Surface preparation and grain size of the specimens tested are negligible. The decarburization rate increases with temperature to the critical range of the steel where it slows down or even decreases. Carbide-forming elements slow the decarburization rate; others have no effect unless they increase the diffusion rate of C in austenite. Mass transfer to the container is possible but unlikely except where appreciable temperature gradients exist. Elimination of graphite flakes from cast iron surfaces at high temperature is more likely than by dissolution in the Na. Oxygen accelerates the attack of Na on Fe. The ratio of surface area to molten metal volume is important, decreasing as attack rate increases. (T.R.H.)

TID-1180 No. 14-14 1217-1336

2.232

NAA - SR - 1292

SODIUM GRAPHITE REACTOR. QUARTERLY PROGRESS REPORT [FOR] OCTOBER-DECEMBER 1954. SECTION A. A. B. Martin, ed.; SECTION B. Guy M. Inman, ed. May 15, 1955. Dec. 28, 1957. 133p.

Latest development results and specifications for SRE fuel elements, moderator and reflector cells, core structure, Na coolant system, control rod system, safety device systems, and instrumentation are presented. A leak detector capable of detecting  $10^{-8}$  moles Na/liter  $N_2$  at atmospheric pressure is described. Revised ring and loading face shielding specifications are briefly discussed, and thermal cycling and Na corrosion tests on thermal shielding material (cast iron) were performed. Twelve thermal insulating materials showed various degrees of deterioration after exposure to molten Na at 950°C for two hr. Tests for determining and maintaining the optimum purification of the inert blanket gas (helium) are described. The fuel handling coffin development studies are summarized.

2.232

TESTING HEAT TRANSFER AND CORROSION OF GLOBEIRON FOR FUEL CLADDING IN A Na-COOLED FAST BREEDER. R. H. Jones and R. E. Lee. Nucleonics 13, No. 2, 70-2(1955). Feb.

Heat transfer and corrosion tests show that Globeiron is satisfactory as a thin-walled fuel-cladding material for 30 day exposures in a sodium-cooled fast reactor. The tests, conducted in the apparatus in Fig. 1, simulated reactor operation in which 500°F sodium entered 0.165-in. -o.d. 10 mil-wall Globeiron tubes was heated in an average heat flux, which was produced by hot NaK, varied from  $1 \times 10^6$  to  $3 \times 10^6$  Btu/ft<sup>2</sup>/hr over the 13½-in. exposed length of specimen.

2.232

Low Cost Materials for Sodium Heat-Transfer Systems by Brush, E. G. and R. F. Koenig (Knolls Atomic Power Lab., Schenectady, N. Y.

The ferritic alloy steels have advantages over austenitic stainless steels in Na-cooled nuclear power plants at temperatures below 1000°F. Resistance to corrosive attack in lab tests indicates satisfactory resistance in Na to mass transfer, to attack by O, to decarburization, and to diffusion bonding at temperatures up to 1000°F.

2.232

NP-5483

REPORT NO. 8 TO DETROIT EDISON COMPANY

May 8 - July 1 1954

J. R. Taylor, S. Sheridan, J. Rodgers, and H. J. Williams  
Sept. 10, 1954. 38 p.

A detailed analysis was made of globeiron tubing exposed for 30 days in a liquid Na corrosion loop. Parts of the loop and samples of Na were examined in order to estimate the effects of corrosion.

- 2.232 ALPLAUS ATMOSPHERIC-PRESSURE SODIUM STILL  
E. E. Baldwin (General Elec. Co., Schenectady, N.Y.). U.S. Atomic  
Energy Comm. KAPL-337, 29 pp. (1950) (Declassified No., 1955).

Results of metallographic examination of an 18-8 stainless steel, atm.-pressure Na still, operated for a total of 55 days and with about 230 hours at 1600°F are reported. Two fires occurred at inlet argon-line connections. A sponge-like plug was found in portion of inlet line which projected below the surface of liquid Na. This was attributed to localized O contamination of Na and resulting attack of stainless steel. It was also concluded that liquid Na at 1600°F produces negligible attack on 18-8 stainless steel. CA 50-8260e

- 2.232 Monthly Report No. 6, February 1954, to Detroit Edison Company  
R. H. Jones. Mar. 11, 1954. 21 p. NP-5482

Test results were evaluated for a 30-day run on the corrosion of globeiron tubing by liquid Na. A slight grain growth was the only indicated change in the material.

- 2.232 Monthly Report No. 5, January 1954, to Detroit Edison Company.  
R. H. Jones. Feb. 16, 1954. 18 p. NP-5481

The results were evaluated for a 7-day run on the corrosion of globeiron tubing by liquid Na. A slight grain growth was the only indicated change in the material.

- 2.232 Monthly Report No. 4, December 1953, to Detroit Edison Company.  
Jan. 4, 1954. 12 p. NP-5480

Initial operation of a corrosion loop for testing the corrosive effects of liquid Na on samples of globeiron tubing are described. The thermal and hydrodynamic characteristics of the loop system were determined.

- 2.232 (NAVEXOS-P-733 (Rev.))  
LIQUID-METALS HANDBOOK  
Richard N. Lyon, ed. June 1952  
276 p. \$1.25 (GPO); Dp.

This second edition of the Liquid-Metals Handbook incorporates suggested improvements and additional release data. It offers a reasonably complete compilation of information on liquid metals covering the physical properties, industrial utilization, corrosive effects on materials, heat transfer properties, heat transfer systems, heat transfer system components, and availability for production of low-melting point alloys.

- 2.232 TID-5277 (NAVEXOS-P-733)  
LIQUID METALS HANDBOOK: SODIUM-NaK SUPPLEMENT  
Carey B. Jackson, ed.-in-chief. June 1955  
445 p. \$2.00 (GPO); Dept.

This edition of the Liquid Metals Handbook (TID-5277; NAVEXOS-P-733) is devoted entirely to Na and NaK. Fifty authors have contributed material. Aspects of heat treated include natural circulation, forced circulation, boiling, and condensation. System design and component chapters include thermal stress, piping considerations, thermal insulation, heat exchangers and steam generators, heating, and cooling. Applications of Na and NaK technology to the Genie project, the Mine Safety Appliances high-temperature system, and the Experimental Breeder Reactor are described.

- 2.233 CORROSION OF STAINLESS STEEL TUBES BY LIQUID SODIUM SYSTEMS. I. THERMAL CONVECTIONAL CORROSION TESTING APPARATUS.  
Hideo Atsumo (Hitachi, Ltd., (Japan)). Nippon Gen-Shiryoki Gakkaishi, p. 94-9 (Feb. 1962) (In Japanese).

A new type thermal convection corrosion testing apparatus was set up to study liquid sodium corrosion of stainless steel. In order to investigate several factors simultaneously, thermal calculation and structure of the apparatus and welding methods of the test pieces in NaK circulating loops was examined. Long term corrosion testing of 18-8 stainless steel tubes by high temperature NaK was effected quite well by this method.

NSA 16:13538

- 2.233 TYPE 316 STAINLESS STEEL FORCED CONVECTION SODIUM CORROSION LOOP TESTS SSSA-1A1, SSSA-ZC2, SSSA-3C3 AND SSSA-5F1  
R. C. Shaw (Pratt & Whitney Aircraft Division), 20 p., TID-12224 (TIM-490)

Na was pumped through 4 test loops constructed of 316 stainless steel to determine the resistance of this material to corrosion and mass transfer. Results are tabulated for operating temperatures of 1050 and 1600°F. It was tentatively concluded that stainless steel has moderately good mass transfer and corrosion resistance; however, since the tests were of a preliminary nature, confirmation tests are recommended.

NSA 16:16692

- 2.233 HEAT TRANSFER THROUGH MOLTEN MATERIALS  
Inco Corrosion Reporter, v. 9, no. 2, Oct 1962, 13p.

Mechanism of liquid metal corrosion at high temperatures and under pressure in nuclear reactors as a function of solution rate and solubility limit of the solid metal in the liquid. Advantages and limitations of liquid metals as heat transfer media and use of 18-8 stainless steel with Na and NaK and Ni alloy Inor 8 with fluoride salt mixtures. 5 refs.

- 2.233 Summary of Liquid Metal Activities at United Nuclear  
J. M. McKee and H. Steinmetz (NASA-AEC Liquid Metal Corrosion Meeting, Dec. 1961 at BNL)

Determination of oxygen and carbon in Na with results recorded. Boiling Na heat transfer loop, stainless steel in the pump and dump sections, and Cb-1%Zr containment material to 1500°F. TID-7626 (Part 1) (AGN Lib. 2-2786)

- 2.233 NAA-SR-5282  
CARBURIZATION OF AUSTENITIC STAINLESS STEEL IN LIQUID SODIUM  
Anderson, W. J. and Sneesby, G. V.  
Atomics International, Div. of North American Aviation, Inc.,  
Canoga Park, Calif.  
1 September 1960 (Contract AT-11-1-Gen-8)

Results are presented of experimental research concerned with carbon transfer in liquid sodium - 304 stainless steel systems. The general nature of the reactions is discussed, and experimental techniques are described. The carburization rates for the steel were governed by diffusion rates. The content of 304 stainless steel in equilibrium with carbon-saturated sodium varies from 2.68% at 1000°F to 4.35% at 1600°F. Sodium containing 15 to 18 ppm carbon is in virtual equilibrium with uncarburized 304 stainless steel at 1200°F, when the oxygen concentration in sodium is less than 40 ppm. Diffusion coefficients for carbon in 304 stainless steel are presented in the temperature range of 1000°F to 1600°F. A method of using microhardness data from carburized stainless steel specimens for indirectly determining the carbon content of sodium is described.

NSA 14:24508

- 2.233 EFFECT OF 1200°F SODIUM ON AUSTENITIC AND FERRITIC STEELS  
J. W. Mausteller and R. C. Werner. Bi-monthly Progress Report No. 1  
for July and August 1959 (on) THERMAL SHOCK, NITRIDING, STRESSED  
CORROSION, UNSTRESSED CORROSION. Sept. 16, 1959. 22 p. Contract  
AT(11-1)-765, OTS MSAR-59-99, MSA Research Corp., Callery, Penna.

Completion of preliminary designs for a thermal shock loop, a corrosion loop, and a nitriding loop is reported. Stressed and unstressed corrosion studies are scheduled to be carried out in the same system. A literature search was started, and various sites were contacted to avoid duplication of effort. It was found that some work has been done at 1200°F sodium temperature with various oxygen concentrations, however, part of the data is contradictory. Test plans include corrosion testing of Croloy and stainless steel samples as well as similar and dissimilar welds of these materials in 1200°F sodium. (J.R.D.)

NSA 14-3-2695

- 2.233 NP-6220  
Mine Safety Appliances Company, Callery, Pa.  
Test of Proposed Design SIG Bellows in Sodium  
Memo Report 100 by Kennedy, G. E. and E. C. King.  
Dec. 22, 1955. 7p.  
Contract NObs-65426

Twenty stainless steel bellows of the proposed SIG design have been tested, by cycling through a 3 in. stroke, while immersed in approximately 850°F sodium and under external pressure. Sixteen of these bellows were tested at a cycle rate of 12 per min. The last four bellows were tested with a 4 min. time delay between each half cycle. Under these latter conditions, two bellows made by Breeze Manufacturing Company, were cycled without failure in excess of 87,000 times. All the other bellows failed by leaking except one in which the stem bound.

NSA 11:4920

- 2.233 THE EFFECT OF CARBIDE PRECIPITATION AND CARBURIZATION ON THE MECHANICAL PROPERTIES OF TYPE 304 STAINLESS STEEL  
O. C. Shepard, A.I. (NAA-SR-Memo-2576) March 11, 1958.  
9p. OTS.

Carburization of stainless steel in Na takes place mainly by grain-boundary diffusion in the 750° to 1000°F temperature range, while at 1200°F and above, volume diffusion predominates. Mechanical property tests of Type 304 stainless steel which has been carburized in Na at volume diffusion temperature range show increased strength and reduced ductility.

NSA: 15:4284

- 2.233 ANALYSIS OF CYLINDRICAL STAINLESS STEEL CANNED MODERATOR ELEMENTS FOR A SODIUM GRAPHITE REACTOR  
(A.I.) NAA-SR-1990  
W. P. Corcoran, et al., Dec., 15, 1957. Decl. Nov. 9, 1959. 110 p.  
Contract AT-11-1-GEN-8. OTS

NSA 14:4950

- 2.233 NAA-SR-Memo-557  
Compatibility of Sodium and Various Materials of Interest in Reactor Construction  
Bowman, F. E., North American Aviation, Inc., Downey, Calif.  
Jan. 5, 1953. Decl. June 6, 1956

Available data relative to the compatibility of Na and various materials of interest in reactor construction are summarized.

- 2.233 FTD-TT 61-31 (Translation)  
INVESTIGATION OF HEAT RESISTANT ALLOYS, "STRENGTH OF ALLOYS IN  
CONTACT WITH Na."  
S. T. Kishkin and G. P. Benedictova

The mechanical strength of a number of alloys operating in contact with Na was investigated. . . Results showed (for short term tests at 1000°C) that Na-filled samples yielded negligible increase in U.T.S. and a decrease in plasticity of alloys. According to long-term test data the limit of long-time strength of alloys remained the same or increased.

NSA 16:25720

- 2.233 (TIM-490) TID 12224, Type 316 SS Forced Convection Na Corrosion Loop Tests SSSA-1A1, SSSA-2C2, SSSA-3C and SSA-SF1, R. C. Shaw, Pratt & Whitney Division of UAC, Conn., Aircraft Nuclear Eng. Lab, Middletown, Conn. July 2, 1958

General compatibility study of Na with 316 at temperatures from 1050 to 1600°F.

NSA 16:6692

- 2.233 (TIM-573) or (TID 12245) also TIM-435 or TID 12232 dated September 19, 1958, Hastelloy-X Type 316 SS Forced Convection Na Corrosion Loop Test, HXLM-3, R. C. Shaw, P&W AC Div, UAC, Conn. Aircraft Nuclear Engine Lab, Middletown, Conn.) Sept. 23, 1958, Contract AT(11-1)-229

Na was pumped through a loop constructed of Type 316 SS with a Hastelloy-X heater leg and an Inconel pump cell to determine ability of an essentially bimetallic system to resist corrosion and mass transfer. Temperature 1700° to 1050°F. Corrosion Rate: 3.5 mils but deposits of 32 mils (primarily of Cr and Ni.)

NSA 16:15147

- 2.233 TYPE 316 STAINLESS STEEL MATERIAL PROPERTIES SUMMARY  
(TID-11894)  
James Nassau (Pratt & Whitney Aircraft Div., United Aircraft Corp., Hartford, Conn.) Nov 1, 1957 (FXM-3140)

A summary is presented of the properties of Type 316 stainless steel determined at 1200° to 1800°F in air and sodium. The properties are short time yield, ultimate tensile strength, stress-rupture and total creep strengths (in air and sodium), modulus of elasticity, and coefficient of expansion. A comparison is made of tube bursts with uniaxial rupture strength at 1350°, 1570°, and 1650°F; the agreement is good. (D.L.C.)

NSA 15:14730

- 2.233 KAPL-M-RWL-5  
RESULTS OF A KAPL THERMAL STRESS TEST ON A STAINLESS STEEL TUBE  
by R. W. Lockhart and R. G. Kennsion. Dec. 15, 1949, Decl.  
March 9, 1957. 7 p. Contract (W-31-109-Eng-52)

The effect of a repeating or cycling thermal stress on a thin wall stainless steel tube was determined. The apparatus used was essentially a paralleled flow single pass concentric tube heat exchanger with hot Na flowing through the inside of the inner tube and cold Na flowing in the annulus between the inner and outer tubes. It is concluded that the experimental values of Na film coefficients are about 35% lower than predicted but are of the right order of magnitude. A thermal stress varied from zero to 32,000 psi 132 times is insufficient to cause a crack or failure in a stainless steel tube at an average temperature of 540°F.

NSA 12:846

- 2.233 AERE-M/M-148  
Gt. Brit. Atomic Energy Research Establishment, Harwell, Berks, England.  
Metallurgical Investigations of Sodium Heat Transfer RIG. 18p. by  
Ward, A. G. and J. W. Taylor. Feb. 1957.

A study was made of the attack of stainless steel and Ni by Na, both oxygen free and contaminated, at temperatures in the range 300 to 600°C in static and dynamic tests. A number of miscellaneous metallurgical investigations on components taken from a stainless steel/Ni double annulus heat exchange rig are also reported. Under the conditions of test, stainless steel of the 18 wt. % Cr-8 Wt. % Ni type containing free carbide, undergoes considerable attack, both in static and dynamic tests in Na nominally free from and also heavily contaminated with O<sub>2</sub>. From the evidence available it is suggested that the mode of attack consists of a decarburizing action which proceeds intergranularly and modifies the spheroidal carbide in the affected region by diffusion of this phase into the matrix. Under similar test conditions Ni undergoes no detectable corrosion even at the highest temperature. It is recommended that prior inspection be carried out on stainless steel for use in systems containing Na at temperatures above 300°C, to ensure that the steel specification has been fulfilled and, that the material is devoid of free carbide.

NSA 11:9285

- 2.233 NRL-Memo-581  
EVALUATION OF CROLOY STEEL FOR SODIUM USE. B. F. Brown. Mar. 23, 1956.  
14p. Project No. NS200-021.

The resistance of Croloy 2½ to corrosion by Na was studied in thermal convection harps. The results of these tests indicate that there is no mass transfer of Croloy 2½ at 550°C (923°F) maximum temperature with delta T of 175°C (315°F), no decarburization of Croloy 2½, no carburization of Type 347 stainless steel in the presence of Croloy, and no detectable difference in effect of O concentration in Na at 0.003 wt. % and 0.014 wt. %.

- 2.233 NP-7392

STAINLESS STEEL SHOT IN SODIUM. Memo Report 62. M. M. Shrut and  
J. K. Richter. July 1, 1954. 4p. NSA 13:12679 TID 3544

- 2.233 KAPL-M-WMK-2  
Knolls Atomic Power Lab., Schenectady, N. Y.  
Pressure Rise in a Confined Volume of Molten Sodium Upon Addition  
of Heat Knox, W. M. May 20, 1953. 7p. Contract W-31-109-  
Eng-52

The effectiveness of a number of lubricants and treatments in reducing the tendency of stainless steel threads to gall during exposure to Na was determined, using the torque required to loosen bolted assemblies as the criterion. Of the methods tested, only nitriding and carburizing were successful. Additional tests will be made of other methods of preventing galling, which are based on thread contour and clearances.

NSA 11:2452

- 2.233 DYNAMIC CORROSION TEST OF TYPE 347 STAINLESS STEEL IN SODIUM.  
N. G. Mills and R. F. Koenig, Oct. 6, 1950. Decl. Feb. 9, 1956.  
9p. (KAPL-M-NGM-1)

As part of the program to compare various sodium purification treatments, a six-month dynamic corrosion test employing thermal circulation was made with aged and filtered sodium to determine the corrosion and erosion resistance of type 347 stainless steel. The temperature relationships were observed for indications of plugging by metal or oxide deposition. No plugging was encountered although there appeared to be some iron deposited immediately downstream from the cooling fins and in the annulus around the specimen. The results showed that type 347 stainless steel was very resistant to corrosion and erosion in aged and filtered sodium at 500°C (932°F). It was also shown that such a system can be operated with moderate flow rates (0.3 ft/sec) and relatively small openings (3/16 in.) without difficulty.



- 2.233 KAPL-M-EGB-4  
ALPLAUS SURVEILLANCE PROGRAM, Progress Report No. 2. E. G. Brush  
Aug. 29, 1952. Changed from Official Use Only June 26, 1956. 9p.

Type-347 stainless steel and L nickel, considered as construction materials in the Alplaus heat-transfer system, were placed in the system to determine their corrosion resistance to liquid Na and NaK. The specimens were very resistant to attack by Na at 950°F and NaK at 850°F. There was no evidence of mass transfer between the stainless steel and Ni specimens. No transfer of mass from the hot to the cold zones occurred in one year.

- 2.233 ORNL - 1033  
Quarterly Progress Report For Period Ending April 30, 1951  
E. C. Miller and W. H. Bridges, eds.  
Oct. 23, 1951. Decl. October 9, 1959  
82 p. Contract W-7405-Eng-26. OTS.  
Oak Ridge National Lab., Tenn.

The thermal cycling of thorium and uranium in Na-K has shown no real deformation of the thorium, but oxide scale formation with significant penetration did occur. The static corrosion testing of construction materials in a liquid-metal environment has continued. Work has started on the corrosion testing of various materials exposed to fused salts. Dynamic corrosion testing using thermal convection loops containing sodium, lead, and lithium is being carried on jointly with the Experimental Engineering Section of the ANP Division. Stainless Steel types 347, 321, and 310; Inconel; and Haynes Alloy 25 displayed very little attack by sodium in 1000 hr at 1500°C. The welds are still the vulnerable areas, and various welding techniques need investigation to determine the best way to eliminate this source of failure.

NSA 14:2671

---

2.234 Nickel and Cobalt Base Alloys

- 2.234 COMPATIBILITY OF INCONEL WITH BOILING ALKALI METALS  
D. H. Jansen and E. E. Hoffman, Oak Ridge National Laboratory  
Am. Inst. Mining, Met., and Pet. Engrs., Annual Meeting,  
New York, February 18-22, 1962.

Nickel-base alloys have numerous physical and mechanical properties which make them potentially useful for containing alkali metals at elevated temperatures. Alkali metals are currently being considered as working fluids for Rankine-cycle Turbo-generator systems for space power applications. The results of studies to determine the compatibility of Inconel with boiling rubidium, sodium, and potassium at temperatures up to 1600°F for several thousand hours are presented.

- 2.234 EXAMINATIONS OF PUMP IMPELLERS FROM SODIUM AND FUSED SALT PUMP  
ENDURANCE TESTS  
J. H. DeVan (ORNL) April 10, 1961. 13p (CF-61-4-77)

Examination of an Inconel impeller used in Na up to 1250°F showed heavy carburization along exposed surfaces. The cause of carburization may be associated with the type of gas purge utilized for these pumps.

NSA 15:18436

- 2.234 ORNL-2349  
Aircraft Reactor Experiment - Metallurgical Aspects.  
W. D. Manly, et al, Jan. 9, 1958, Decl. Oct. 9, 1959  
57 p. Contract W-7405-eng-26. OTS

Mass transfer, corrosion, and welds of Inconel in sodium.

NSA 14:1762

- 2.234 ORNL-2422, (Secret), Oak Ridge National Laboratory, Tennessee.  
Metallurgy Division Annual Progress Report For Period Ending  
October 10, 1957. December, 1957. 247 p.

... Inconel-Na and Inconel-NaK ... ACR 14:425

- 2.234 CF-54-9-98. ORNL  
Examination of Sodium, Beryllium, Inconel Pump Loops Numbers 1  
and 2. G. M. Adamson and E. Long. Sept. 13, 1954. Decl.  
Oct. 9, 1959. 12p. Contract W-7405-eng-26. OTS.

From data obtained from two loops, the use of beryllium in  
Inconel systems containing molten sodium appears feasible if the tempera-  
ture is held below 1200°F. NSA 14:2690

- 2.234 ORNL-1934  
AN EVALUATION OF CORROSION AND OXIDATION RESISTANCE  
OF HIGH TEMPERATURE BRAZING ALLOYS  
E. E. Hoffman, P. Patriarch et al., Oak Ridge

Many of the brazing alloys which were investigated were highly  
promising for Na-to-air service. Alloy systems of Ni-Si-B, Ni-Cr-Si-B  
and Ni-Cr-Si\* were especially favorable. Precious metal alloys were in  
general severely attacked by Na as were many of the Si-free, Cr-free, P  
bearing alloys. Alloys containing Mo, Sn, or Cu exhibited poor resistance  
to oxidation at 1500°F. In most cases, oxidation was more pronounced at  
1700°F.

\* There is a Microbrazed-130 with 10 Si 19Cr balance Ni (0.1C) solidus liquid  
1975, 2175 - 2075°F recorded temperature.

CA 55:16372f

- 2.234 ORNL-1033  
Quarterly Progress Report For Period Ending April 30, 1951  
E. C. Miller and W. H. Bridges, eds.  
Oct. 23, 1951. Decl. October 9, 1959  
82 p. Contract W-7405-Eng-26. OTS.  
Oak Ridge National Lab., Tenn.

The thermal cycling of thorium and uranium in Na-K has shown no  
real deformation of the thorium, but oxide scale formation with significant  
penetration did occur. The static corrosion testing of construction materials  
in a liquid-metal environment has continued. Work has started on the  
corrosion testing of various materials exposed to fused salts. Dynamic  
corrosion testing using thermal convection loops containing sodium, lead,  
and lithium is being carried on jointly with the Experimental Engineering  
Section of the ANP Division. Stainless Steel types 347, 321, and 310;  
Inconel; and Haynes Alloy 25 displayed very little attack by sodium in  
1000 hr at 1500°C. The welds are still the vulnerable areas, and various  
welding techniques need investigation to determine the best way to eliminate  
this source of failure. NSA 14:2671

- 2.234 KAPL-M-EG-4  
ALPLAUS SURVEILLANCE PROGRAM. Progress Report No. 2. E. G. Brush  
Aug. 29, 1952. Changed from Official Use Only June 26, 1956. 9 p.

Type-347 stainless steel and L nickel, considered as construction  
materials in the Alplaus heat-transfer system, were placed in the system to  
determine their corrosion resistance to liquid Na and NaK. The specimens  
were very resistant to attack by Na at 950°F and NaK at 850°F. There was no  
evidence of mass transfer between the stainless steel and Ni specimens. No  
transfer of mass from the hot to the cold zones occurred in one year.

2.235 Refractory Metals

- 2.235 BNL-728  
OXYGEN-EXCHANGE THERMODYNAMICS IN LIQUID METAL CORROSION  
J. R. Weeks, Brookhaven National Laboratory, 1962.

Oxygen-exchange may promote embrittlement of the container metal by formation of container-metal oxides which may precipitate internally after oxygen diffusion, as Cb, Ta, Zr by Na + O or K + O.

- 2.235 AGC-SRP-R-397  
CORROSION RATES OF REFRACTORY METALS EXPOSED TO NOZZLE COOLANTS.  
C. J. Westcoat, Aerojet-General Corporation, SRP Report No. M & F 397, 1 April 1962. Contract No. Nord 17017.

This report summarizes the results of a program to determine the corrosion rates of unalloyed tungsten, tantalum, and molybdenum, and 90% tantalum - 10% tungsten alloy, columbium - 1% zirconium alloy, and C103 columbium alloy exposed to molten lithium, sodium, potassium, and magnesium. Rectilinear and Arrhenius plots of all systems are presented up to the boiling point of the molten metals at one atmosphere pressure. The feasibility of cooling nozzles by molten alkali metals has been proven from the viewpoint of corrosion.

- 2.235 (NP 11824) Evaluation of a High Str. Nb Alloy AS-55 for Alkali Metal Containment. Quart. Report #2 Feb. 25, 1962 - May 25, 1962  
G.E. Co., F. P. L. Dept. Cincinnati. Cont. NAS 3-2140 83p.

Activities are described in a program to determine the properties of Nb-base alloys for alkali metal containment materials in nuclear turbo-electric space power systems. The material being investigated has a nominal comp. of Nb, 5% W, 1% Zr, 0.06% C; with a 1% Y addition. The program status is reported concerning the arc melting investigation, ingot conversion evaluation of AS-55 sheet, and corr. testing. NSA 16:24165

- 2.235 ANL 6268 Development of Liquid-Phase Sintering Techniques for Mo Alloys. Argonne National Laboratory

An envelope-type microstructure produced by phase sintering techniques was used to develop ductile Mo-base alloys for Na-cooled fast reactor application. A total of 105 compositions were examined .... Two compositions based on the Mo-W-Ni and W-Cr-Ni systems, respectively, appear to hold promise as potential canning materials for sodium-cooled fast reactor application. NSA 16:24145

- 2.235 Summary of Liquid Metal Activities at United Nuclear  
J. M. McKee and H. Steinmetz (NASA-AEC Liquid Metal Corrosion Meeting, Dec. 1961 at BNL)

Determination of oxygen and carbon in Na with results recorded. Boiling Na heat transfer loop, stainless steel in the pump and dump sections, and Cb-1%Zr containment material to 1500°F. TID-7626 (Part 1) (AGN Lib. 2-2786)

- 2.235 NASA TN-D-769, 1960  
SODIUM LIQUID AND VAPOR PHASE CORROSION STUDIES  
NRL - Washington, D. C., T. A. Kovacina.

Thermal properties of Na, Na corrosion of Cb-1Zr is reported, analysis by radiochemical methods.

- 2.235 QUARTERLY STATUS REPORT ON LAMPRE PROGRAM FOR PERIOD ENDING NOVEMBER 20, 1960  
(LASL) Dec. 1960, 29 p. Contract W-7405-eng-26. (LAMS-2487)

Abstract refers to thermocouple failure, the cover gas system, and tantalum corrosion in sodium. NSA 14:8345

- 2.235 Behavior of Rubbing Molybdenum Surfaces in Sodium Environments  
Kissel, John W., Melton, Carl W., Glaeser, William A.  
Battelle Memorial Institute, Columbus, Ohio  
U.S. Atomic Energy Commission BMI-1405, 23pp. (1960)

A study of Mo sliding against itself in liquid Na yields interesting evidence to support a reacted-surface film hypothesis for the mechanism of lubrication of Mo by liquid Na. Na influences the sliding behavior of Mo by modifying reacted films which provide boundary lubrication. These effects are temp. dependent. The sliding specimens consisted of a ball and a flat rectangle. Operating conditions were Na temps. of 250-1300°F., sliding speeds of 0.22 to 2.5 mm/sec, and contact stresses of 80,000 lb/sq in. The addn. of clean Na between dry Mo rubbing surfaces in an Ar atm. of high purity produces a marked drop in friction coeff. and the character of the wear scar changes from galling to superficial scratching. These effects persist after the removal of Na by evapn. Studies of the films were conducted by using electron and x-ray diffraction, electron microscope, and differential thermal analysis techniques. A film of Na<sub>2</sub>-MoO<sub>4</sub> on the Mo surfaces provides low friction and diminished surface damage. Examn. in vacuum up to 10<sup>-6</sup> mm. Hg demonstrates that the native oxides, MoO<sub>3</sub> and MoO<sub>2</sub>, also influence its sliding behavior.

CA 54:14038f

- 2.235 PWAC-583 (Secret)  
Pratt and Whitney Aircraft Division, United Aircraft Corporation,  
Middletown, Connecticut  
NUCLEAR PROPULSION PROGRAM ENGINEERING PROGRESS REPORT FOR JULY 1,  
1958 - SEPTEMBER 30, 1958. October, 1958. 124 p.  
...compatibility tests of Mo in Na; compatibility tests in  
lithium of iron and nickel base alloys ....

ACR 15:174

- 2.235 LA-2327 Uncl.  
Los Alamos Scientific Laboratory, New Mexico  
LOS ALAMOS MOLTEN PLUTONIUM REACTOR EXPERIMENT (LAMPRE) HAZARD  
REPORT.  
E. O. Swickard, comp. June 1959. 115 p.  
.... corrosion of Ta by Na ....

NSA 14:6035

- 2.235 CORROSION AND CREEP BEHAVIOR OF TANTALUM IN FLOWING SODIUM.  
Gilbert E. Raines, C. Vernon Weaver, and John H. Stang (Battelle  
Mem. Inst., Columbus, O.). U.S. Atomic Energy Comm. BMI-1284,  
29pp. (1958).

Ta tabs were suspended 8 to 50 days in the hot leg of Na pumped loops of type 316 stainless steel having max. temp. 1200°F. and min. 500 to 1000°F. In Na continuously gettered with Zr, wt. loss of Ta corresponded to 0.1 mil per year, and in Na continuously cold-trapped, 3 mils per year. Metallographic examn. indicated no localized attack except for severe intergranular attack of one group of arc-cast material exposed to Na high in O. During exposure O showed considerably stronger tendency to migrate from Ta to Na than predicted from available thermodynamic data. Creep tests at 1200° showed little if any difference whether conducted in He or in a pumped loop contg. Na continuously gettered with Zr.

NSA 12:16355

CA53-3011e

- 2.235 390 IGR-TN/C-1019 UNCLASSIFIED  
United Kingdom Atomic Energy Authority. Industrial Group. Culcheth  
Labs., Culcheth, Lancs, England  
Corrosion of Niobium and Vanadium in Liquid Sodium.  
Evans, J. W. and A. Thorley 1958. 37p.

The results of work on the corrosion of niobium and vanadium in flowing sodium at low oxygen levels obtained by hot-trapping with zirconium titanium, and magnesium are presented. In relation to the behavior of the canning materials within the core at start-up and during the "clean-up" period, the corrosion of niobium and vanadium was investigated at the temperatures of "clean-up" starting from high oxygen values. Also, the effect of oxide films from weld areas on the oxygen content of the primary circuit during clean-up was examined. (auth)

TID-1197 No. 15-6  
359-462

- 2.235 Bett, F. L., COMPATIBILITY BETWEEN SOLID AND LIQUID METALS, Australian Atomic Energy Symposium paper, pp 201-205, (1958)  
See Review of Metal Literature Vol 18 (7), 46.

Definition, reduction and assessment of compatibility between solid and liquid metals illustrated by investigation into compatibility of Cb with liquid Na.

- 2.235 Fabrication and Properties of Niobium  
Williams, L. R. and Heal, T. J.  
Third Plansee Seminar Proceedings (1958)

The corrosion rates of columbium in sodium were found to be insensitive to the metal condition or the surface condition, but highly sensitive to oxygen content, the flow of velocity, and the temperature.

- 2.235 BMI-1220 (Conf.)  
Battelle Memorial Institute, Columbus, Ohio  
PROGRESS RELATING TO CIVILIAN APPLICATIONS DURING AUGUST 1957  
R. W. Dayton and C. R. Tipton, Jr. September 1957. 60p.  
....corrosion of Ta in Na-flow loops ....

ACR14:267

- 2.235 PROGRESS RELATING TO CIVILIAN APPLICATIONS DURING JUNE 1957  
BMI-1201  
R. W. Dayton and C. R. Tipton, Jr. July 1, 1957. Decl.  
March 30, 1960. 52 p. Contract W.7405-eng-92. OTS.

Includes studies of Na-Ta compatibility at elevated temperatures.

NSA 14:21881

- 2.235 BMI-1189 Uncl.  
Battelle Memorial Institute, Columbus, Ohio.  
PROGRESS RELATING TO CIVILIAN APPLICATIONS DURING MAY 1957  
R. W. Dayton and C. R. Tipton, Jr. June 1957. 59 p.  
...Ta exposed to 1200°F peak temperature sodium....

NSA 14:19310

- 2.235 BMI-1152 Uncl.  
Battelle Memorial Institute, Columbus, Ohio  
PROGRESS RELATING TO CIVILIAN APPLICATIONS DURING DECEMBER 1956  
R. W. Dayton and C. R. Tipton, Jr. January, 1957. 83p.  
... Na-Ta compatibility at high temperatures ....

NSA 14:21879

- 2.235 Report No. 9, July 1, 1954 to September 1, 1954, to Detroit Edison Company. J. R. Taylor, Sheridan J. Rodgers, and H. J. Williams.  
Sept. 30, 1954. 26 p. (NP-5484).

Liquid sodium corrosion tests are described for two Ti tube specimens. Both specimens. Both specimens failed by oxide formation along grain boundaries with erosion of TiO<sub>2</sub> at the hot end of the corrosion loop where turbulence was greatest. O<sub>2</sub> was absorbed from the liquid Na and NaK.

- 2.235 LIQUID METALS HANDBOOK; Na - NaK SUPPLEMENT  
Carey B. Jackson, ed.-in-chief. June 1955. 445 p.  
(TID-5277; NAVEXOS-P-733). \$2.00 (GPO); Dept.

This edition of the Liquid Metals Handbook (TID-5277; NAVEXOS-P-733) is devoted entirely to Na and NaK. Fifty authors have contributed material. Aspects of heat transfer treated include natural circulation, forced circulation, boiling, and condensation. System design and component chapters include thermal stress, piping considerations, thermal insulation, heat exchangers and steam generators, heating, and cooling. Applications of Na and NaK technology to the Genie project, the Mine Safety Appliances high-temperature system, and the Experimental Breeder Reactor are described.

- 2.236 NAA-SR-6674  
OXIDATION OF Zr AND Zr ALLOYS IN Na(1)  
 I. L. Mackay (1962)

A weight gain technique was used to study oxidation of Zr and 8 Zr alloys at 400° to 635° in a static Na(1) system with a concentration of ~10 ppm of O. A transition from a parabolic to a linear oxidation rate was observed at 400° to 500° for all alloys except Zircoloy-2. At >500° the transition was not observed and a protective film continued to form. Activation energies of  $52.9 \pm 0.5$  K-cal/mole for Zr and  $45.3 \pm 1.5$  K-cal/mole for alloys were obtained by the use of the parabolic rate eq. to describe the kinetics of oxidation.

- 2.236 EFFECT OF SODIUM EXPLOSURE ON THE MECHANICAL PROPERTIES OF ZIRCONIUM  
 J. C. Bokros (General Atomic Div., General Dynamics Corp., San Diego, Calif.) Corrosion 17, 31t-4t (1961) Jan.

It was found that surface oxides which developed on zirconium in impure Na significantly lowered the fatigue life at elevated temperatures. H<sub>2</sub> adsorption had little effect on the fatigue life at elevated temperatures but lowered the fatigue life at room temperature. Tensile properties of Zr at elevated temperatures was not significantly altered.

NSA 15:6405

- 2.236 (CA56:13737c) "Zirconium Alloys for Cladding High Temperature Fuel Element" R. K. Wagner, et al. Met. Soc. Am. Inst. Mining and Met. Petrol Engrs., Inst. Metals Division Spec. Rept. Ser. 7 No. 10,33-7 (1960)

Several zirconium alloys were prepared by std. methods and fabricating techniques. To evaluate these alloys, tensile tests were made at R. Temp. 1050 and 1200°F. Alloying produced a signif. strengthening effect on Zr at R.T. and elevated temperatures. The Zr creep str. is substantially improved by alloying. The stress levels employed for many of the creep tests exceeded the 1050°F yield str. of realloyed Zr. The corrosion behavior in molten Na was established for 2 alloys (1.5 Al-1.5 Sn-1.5 Mo and 1.25 Al-1 Sn-1 Mo) and for unalloyed Zr. Exposure was made in agitated or circulated Na at 2 temperatures 1000°F and 1200°F. Very little difference exists between the corrosion rate of the alloys and unalloyed Zr. The macroscopic Zr cross-section was affected slightly by addition of various alloying elements. The more significant changes are noted in alloys containing 15-18% Nb.

- 2.236 AN APPARATUS FOR OBSERVING CRACKING AND CREEP IN ZIRCONIUM ALLOY SPECIMENS WHEN IMMersed IN MOLTEN Na or NaK  
 (NAA-SR-Memo-5261)  
 D. M. Lonneaux (AI) May 6, 1960. 4p. OTS.

A study was made of vessel designs to test zirconium alloy specimens under tensile stresses sufficient to produce 2% elongation while immersed in molten alkali metals and to externally measure the creep of the specimens.

NSA 15:6202

- 2.236 NAA-SR-3481 Uncl.  
 Atomics International Division, North American Aviation, Inc.  
 Canoga Park, California  
HIGH-STRENGTH ZIRCONIUM ALLOYS. R. K. Wagner and H. E. Kline.  
 July, 1959. 40 p.

... corrosion resistance in sodium ....

NSA 13:18104

- 2.236 Corrosion of Beryllium in Flowing Sodium  
Kendall, W. W. General Electric Co., Atomic Power Equipment Dept.  
(San Jose) GEAP-3333, January 15, 1960, 30 p. (Contract AT(04-3)-  
189 NSA 14:15940

Samples of seven types of fabricated beryllium were exposed to sodium flowing at 20 ft/sec at 900°F for 47 hours followed by 520 hours at 1000°F. The oxide content of the sodium was first reduced by cold-trapping and then gettering with about 1% calcium. On completion of the test, all samples were found to be nitrided and some were joined together at points where the beryllium had been in contact with beryllium. Variation in behavior between the different samples was not apparent. The Be<sub>3</sub>N<sub>2</sub> film was the thickest (~50 microns) on the face exposed to high velocity sodium. The Be<sub>3</sub>N<sub>2</sub> film was black, hard, and adherent. The beryllium below the surface film did not appear to be affected by exposure to sodium.

- 2.236 CA56 8260 h "Non-Ferrous Metals as Construction Materials in a Reactor" by E. Gebhardt. Atomivirtschaft 6447-8 (1961)  
I. A review of phy. prop. of Be.  
II. Ibid 545-50(1961) Review of Prop. of Al, Mg and Zr and of Na as liquid coolant. Data on corrosion of Fe by Na(l) at 650°C are given.

- 2.236 Solid Metal-Liquid Metal Reactions in Bismuth and Sodium  
J. R. Weeks and D. H. Gurinsky, p 114 of Liquid Metals and Solidification, Pub. ASM, Novelty, Ohio, 1958

The effect of dissimilar metals in contact with the melt is reported from a few experiments of this type.

- 2.236 The Compatibility of Beryllium with Liquid Sodium and NaK in Dynamic Systems  
Bett, F. L. and Draycott, A. (Australia) 16 p.  
A/CONF. 15/P/1091, 1958, v7

The mechanism of corrosion of beryllium in oxygen-bearing sodium and NaK is briefly discussed. Experiments are described which measure the rate of corrosion of beryllium in cold-trapped NaK. These corrosion rates are found to be excessive. As oxygen in the liquid metal is considered to be the cause of the corrosion, cold trapping is supplemented by hot trapping as a means of deoxidation of NaK in a second series of experiments. These experiments show that with a thorium hot-trap reduced corrosion of beryllium occurs compared with cold-trap conditions, but is still excessive. Calcium, however, when used in the hot-trap reduces beryllium corrosion to an acceptable level. At the levels required for successful hot-trapping calcium removes negligible quantities of nickel from stainless steel which can therefore be used as a container material.

NSA 13:6787

- 2.236 BNL-489  
RECENT INFORMATION ON MODERATOR SHEATH CORROSION IN LIQUID SODIUM  
Atomics International Division, North American Aviation, Inc.,  
Canoga Park, California.  
R. L. Eichelberger. p. 168-73 of Proceedings of the French-American Conference on Graphite Reactors held at Brookhaven National Laboratory, November 12 to 15, 1957.

NSA 13:3965

- 2.236 NAA-SR-Memo-1115  
The Investigation of the Effects of Sodium on SRE Core Materials  
Bowman, F. E.  
North American Aviation, Inc., Downey, Calif. Oct. 4, 1954.  
Decl. June 6, 1956. 5p.

An experimental program to investigate sodium effects at elevated temperatures on Zr in order to establish the feasibility of using Zr in a sodium system at temperatures above 1000°F was proposed and outlined.

- 2.236 Corrosion of Uranium, Thorium, and Uranium Alloys in Sodium and Organics. Harry Pearlman. p. 565-87 of Fuel Elements Conference, Paris, November 18-23, 1957. 23 p. (TID-7546; NAA-SR-Memo-2169) \$7.00(OTS). TID 3544 NSA 12:9444

- 2.236 NAA-SR-1867 Atomics International Div., North American Aviation, Inc., Canoga Park, Calif. Effect of Sodium on the Mechanical Properties of Zirconium by Bokros, J. C. June 15, 1957. 39p. Contract AT-11-1-GEN-8

Zirconium is useful as a structural material in nuclear reactors, and is employed in contact with high temperature liquid Na. It was found that surface oxide which develops on Zr in Na significantly lowers the fatigue life at elevated temperatures. Hydrogen on the other hand has very little effect on the fatigue life at elevated temperatures but lowers the fatigue life at room temperature. It was also found that exaggerated grain growth which occurs above 950°F in Zr severely reduces the fatigue life at elevated as well as low temperatures. The effect of Na, i.e., the pick-up of surface oxide and reasonable amounts of H<sub>2</sub>, does not significantly alter the tensile properties of Zr at high temperature. Data also indicate that Zr is stable to dimensional changes after thermal cycling.

NSA 11:9330

- 2.236 BW-7050  
Ferguson, K. Mildred (Babcock and Wilcox Co. Research Center, Alliance, Ohio) Metallurgical Investigation of Fuel Element Pins Tested in Liquid Sodium. 1957. 33 pages

Of the pins tested for corrosion resistance in sodium, the most promising ones were those with a swaged end cap. Although the pins swaged to a point appeared good visually, they contained deep folds vulnerable to marked attack. Pins capped by two methods obviously are unsatisfactory; the screw-cap mechanism and the countersunk cap locked by pressure both permit free circulation of sodium to the core alloy. The countersunk and welded method would be improved by a closer fit between cap and pin. Corrosion resistance of the pins capped by the resistance-welded method is determined by the pressure or absence of mechanical defects produced by welding. All zirconium surfaces in contact with freely circulating sodium developed the hard and brittle surface layer attributed to the absorption of oxygen into solid solution. All exposed core alloys oxidized during test. It has been proven that the formation of the hard and brittle surface layer on zirconium exposed to sodium is not related to the frequently observed mechanically deformed surface layer. Its formation is independent of prior surface condition.

NSA 12:7809

- 2.236 Corrosion of Zirconium in 1000 F Sodium  
Rodgers, S. J. and J. W. Mausteller  
Mine Safety Appliances Company, Callery, Penna. Memo Report 110  
Contract NObs-65426. April 23, 1956. 5p.

The corrosion of Zr was studied as a function of oxygen concentration in 1000 F sodium flowing at 3 fps in a Ni system. The corrosion rate varied from 0.8 mg/cm<sup>2</sup>-Mo at 0.005 wt% O<sub>2</sub> to 1.0 mg/cm<sup>2</sup>-Mo at 0.035 wt % O<sub>2</sub>. Samples were covered with a black film and all showed weight gains.

- 2.236 KAPL-M-FWW-1  
Knolls Atomic Power Lab., Schenectady, N. Y.  
The Stress-Rupture Strength of Zirconium-Base Alloys in Sodium at 1000°F (538°C)  
Baldwin, E. E. and F. W. Weisinger. October 14, 1954. 26p.  
Contract W-31-109-Eng-52

Stress rupture tests were conducted in Na at 1000°F) on Zr-Base binary and ternary alloys. The test results indicated that the alloys had rupture strengths higher than Zr but lower than Type 347 stainless steel, and that the highest rupture strength was exhibited by an alloy containing 1.7% Al.  
NSA 10:10849.



- 2.236 KAPL-M-HLT-1  
Knolls Atomic Power Lab., Schenectady, N. Y.  
Wear and Galling Tests of Plug Seal Tubing, Report No. 1  
Brush, E. G. and H. L. Tymchyn. Feb. 25, 1954. 16 p.  
Sub-Project No. 27, Contract W-31-109-Eng.-52.

To determine the effect of Cr plating on the wear and galling characteristics of the plug seal tubing laboratory tests simulating the sliding action of the rotating plug during raising and lowering operations have been completed in Na at 500°F. Cr plated and as drawn tubing sections, loaded to deflections of 15 and 30 mils, were drawn over plates representing the container wall under conditions simulating 355 plug raising and lowering operations. Results indicate that sizing due to galling is unlikely in SIR and that for deflections in the range of 0 to 20 mils as drawn tubing has satisfactory resistance to wear and scoring. Above 20 mil. deflections Cr plating will reduce the amount of scoring and wear experienced by both tubing and container wall. NSA 10:10822

- 2.236 NAA - SR - 1109 (Rev.)  
Sodium Graphite Reactor Quarterly Progress Report For  
July-September, 1954. Sidney Siegel and Guy M. Inman, eds.  
Dec. 1, 1954. Decl. Mar. 4, 1957. 101 p.

Data on the transfer of radioactivity from Zr by Na has been obtained from a capsule of the first series of three miniharps. Fe, Al, and Cu were immersed in toluene and irradiated at 150°F in the MTR-Gamma canal. Toluene is being considered as a shield coolant for the SRE. The effect of 1-Mev electron irradiation on terphenyls was also studied. Manville Brick C-16 (Sil-O-Cel mortar), Superex Paste, and Eagle-Picher Mineral Wool were subjected to liquid Na to study deterioration effects. Encouraging results were obtained in an effort to evaluate the effectiveness of Na decontamination by liquid ammonia. Pressure drop and flow characteristics of the latest design SRE fuel element have been completed. Gamma dose rates at the surface of the top shield were measured, together with the heat generation in the top thermal and biological shields.

- 2.236 NAA-SR-Memo-758  
North American Aviation, Inc., Downey, California  
Proposed Program to Provide Design Data for Zirconium for Use in a  
Zirconium-Graphite-Sodium Reactor System.  
Bowman, F. E., August 7, 1953. Decl. June 6, 1956 13p.

A brief resume of the strength and sodium corrosion data that have been found available in the classified literature is given. Tensile properties of Zr and Zr alloys at 500°F, comparison of room temperature and 500°F tensile and creep properties of various Sn-Zr alloys, stress rupture of Zr-Al alloys in Na at 1000°F and a proposed research program are included.

NSA 11:1129

---

2.237 Nonmetallic Materials

- 2.237 REPORT ON SODIUM COMPATIBILITY OF GRAPHITES AND SEMI-GRAPHITES  
L. R. Kovac (Atomic Power Development Associates, Inc., Detroit).  
July 27, 1962. 15 p. (NP-12487).

Tests were made to measure the total Na absorption and volume expansion of several types of graphites and semigraphites immersed in liquid Na at 500, 700, and 900°F in restrained and unrestrained conditions for periods up to 336 hr. The results show that the total Na absorption volume is approximately equal to the sum of swelling and void volumes, except for anomalies at 700°F. The rate of Na absorption and swelling was found to be rapid, the absorption being complete within the first 24 hours. The total amounts of Na absorption and swelling increase with temperature and are greater for the semigraphites than for the graphites. It is concluded that the graphite shield design should have provision for 5% volume increase in the event of a catastrophic Na leak into the shield tank.

NSA 17:8709

2.237

TID 14979 Glass Fabric Switch Test on Na and NaK Fumes for Atomics International, American Air Filter Co., Louisville, June 9, 1961.

Tests were made on the feasibility of using a glass bag cloth collector for removing Na and NaK fumes.

NSA 16:12660

2.237

TID-7626 (Part 1)  
DETERMINATION OF CARBON IN SODIUM-DEPOSITION OF REFRACTORY COATINGS FROM LIQUID METAL MEDIA-PROPERTIES OF MATERIALS EXPOSED TO 1200° F Na  
J. W. Mausteller and F. Tepper (MSA)  
(NASA-AEC Liquid Metal Corrosion Meeting, Dec. 1961 at BNL)

Analysis by Van Slyke oxidation - preparation of coatings that would resist liquid metal attack - Type 316 SS and 2-1/4 Cr-1Mo in two dynamic loops, test conditions recorded.

AGN-2786

2.237

NAA-SR-6094, Sodium-Graphite Interaction and Graphite Protective Coatings, Gill, J. J., (May 1, 1961).

Molten Sodium attacks artificial graphites causing dilation and, under some conditions desorption. Because of the anisotropy of extruded graphite, dilation perpendicular to the extrusion axis is slightly greater than parallel to the extrusion axis. At 600 to 1000° F, sodium is initially nonwetting to graphite, but becomes wetting in a matter of minutes.

The liquid soaks into the pores of the graphite through chemisorption and intergranular penetration; interlamellar compounds or complexes may also be formed. Coatings and coating techniques were investigated for the protection of graphite from attack by molten sodium. The coatings examined included chromium, nickel, zirconium, zirconium carbide, tungsten carbide, silicon carbide, silicon nitride, moly disilicide. None of the coatings, tested by soaking in static sodium at 1000° F, gave satisfactory protection. Failure in all cases resulted from continuous porosity cracks in the coating material.

2.237

ORNL-2391  
Corrosion Resistance of Various Ceramics and Cermets to Liquid Metals  
Cook, W. H. U. S. Atomic Energy Commission  
June 15, 1960, 26p. Rev. of Metal Literature, Vol. 17, No. 9, 546-R, (Sept. 1960)

The results of corrosion screening testing on boride, carbide, nitride, oxide and silicide ceramics and tungsten carbide and titanium carbide base cermets exposed for 100 hr. to Li, Na and Pb metals at 1500° F.  
(R6m;6-70, NM-f)

NSA 14:24510

2.237

AD278425 (AFOSR TN60-871) Research & Advanced Development Division, Avco Corp., Wilmington, Mass. The Reaction of Glasses, Pyrolytic Graphite, & Selected Refractories with Sodium Vapor at Elevated Temperatures. Michael Imnat April 1960.

The material Vycor, Pyrex, boron nitride, Al<sub>2</sub>O<sub>3</sub> (Morganite), BeO MgO (99% dense) Al<sub>2</sub>O<sub>3</sub> (fully dense) and pyrolytic graphite were exposed to Na vapor at a measured temperature of 940° C (1725° F) for a period of 15 minutes. The complete loss of the Vycor sample, structural disintegration of pyrolytic graphite reaction of Pyrex; and diffusion of Na into the less dense ceramics was observed. A corrosive reaction of type 304 SS was observed where it was in contact with the Vycor sample. The test shows the need for dense ceramics where Na vapors are to be in contact with alkali metal propulsion system components.

- 2.237 CORROSION RESISTANCE OF VARIOUS CERAMICS AND CERMETS TO LIQUID METALS. W. H. Cook USAEC Report ORNL-2391, June 15, 1960.

Ceramics in Na to 1500°F and Type 316 stainless steel in K to 1550°F.

- 2.237 TERNARY LAMELLAR COMPOUNDS OF LITHIUM OR SODIUM WITH GRAPHITE  
Marceline L. Dzurus, et al., (ANL) p. 165-8 of "Proceedings of the Fourth Conference on Carbon." New York, Pergamon Press, 1960.

It was found that very pure sodium does not appear to react with graphite at temperatures up to 450°C. However, it is believed that impurities occupy so-called "spacer" positions in the lattice and thus facilitate the intercalation of sodium.

NSA 15:8657

- 2.237 The Chemical And Physical Interaction of Sodium and Graphite  
Asher, R. C., Atomic Energy Research Establishment (Gt. Brit.)  
AD-207-917L Div. 4, August 1958, 23 p. illus. 44 refs.  
AERE Report No. CE/R 2618; HX 58/1093, TAB No. U59-9, 1 May 1959, page 1994

The previous literature on the interaction of sodium and graphite, which is of importance in connection with sodium-cooled, graphite moderated reactors, is discordant. The present work shows that there is chemical interaction to form a lamellar compound of ideal formula  $C_{64}Na$ . This involves a 5% increase in the average interplanar spacing of the graphite and this in turn causes a dilation of the graphite and, frequently, a disruption of the graphite artefact. The magnitude of the dilation can be predicted from the thermal expansion data. The evidence for compound formation is mainly X-ray crystal-lographic, supported by magnetic susceptibility determinations.

- 2.237 LAMELLAR COMPOUND OF SODIUM WITH GRAPHITE  
R. C. Asher and S. A. Wilson (Atomic Energy Research Establishment, Harwell, Berks, England, Nature 181, 409-10 (1958) Feb. 8

Contrary to theoretical and experimental expectations, recent work provided evidence for the existence of a lamellar compound of Na with graphite. The compound was prepared by heating powdered graphite with about 3% Na at about 400°C for one hour with continuous stirring. The conditions are not critical. X-ray diffraction studies indicated the formation of a compound by the absence of several diffraction lines strongly characteristic of graphite. A second indication of compound formation was the definite composition of the product, probably  $C_{64}Na$ . The probable structure of the compound is suggested, but a detailed analysis is necessary before the structure can be definitely defined.

NSA 12:5396

- 2.237 NAA - SR - 1292  
SODIUM GRAPHITE REACTOR. QUARTERLY PROGRESS REPORT [FOR] OCTOBER-DECEMBER 1954. SECTION A. A. B. Martin, ed.; SECTION B. Guy M. Inman, ed. May 15, 1955. Decl. Feb. 28, 1957. 133p.

Latest development results and specifications for SRE fuel elements, moderator and reflector cells, core structure, Na coolant system, control rod system, safety device systems, and instrumentation are presented. A leak detector capable of detecting  $10^{-8}$  moles Na/liter  $N_2$  at atmospheric pressure is described. Revised ring and loading face shielding specifications are briefly discussed, and thermal cycling and Na corrosion tests on thermal shielding material (cast iron) were performed. Twelve thermal insulating materials showed various degrees of deterioration after exposure to molten Na at 950°C for two hr. Tests for determining and maintaining the optimum purification of the inert blanket gas (helium) are described. The fuel handling coffin development studies are summarized.

- 2.237 NAA - SR - 1109 (Rev.)  
Sodium Graphite Reactor Quarterly Progress Report For  
July-September, 1954. Sidney Siegel and Guy M. Inman, eds.  
Dec. 1, 1954. Decl. Mar. 4, 1957. 101 p.

Data on the transfer of radioactivity from Zr by Na has been obtained from a capsule of the first series of three miniharps. Fe, Al, and Cu were immersed in toluene and irradiated at 150°F in the MTR-Gamma canal. Toluene is being considered as a shield coolant for the SRE. The effect of 1-Mev electron irradiation on terphenyls was also studied. Manville Brick C-16 (Sil-O-Cel mortar), Superex Paste, and Eagle-Picher Mineral Wool were subjected to liquid Na to study deterioration effects. Encouraging results were obtained in an effort to evaluate the effectiveness of Na decontamination by liquid ammonia. Pressure drop and flow characteristics of the latest design SRE fuel element have been completed. Gamma dose rates at the surface of the top shield were measured, together with the heat generation in the top thermal and biological shields.

- 2.237 NAA - SR - Memo - 1171  
Effect of Molten Sodium on Thermal Insulation Specimens  
Tarpinian, M., North American Aviation, Inc., Downey, Calif.  
November 19, 1954, 8 p.

Every type of thermal insulating material tested showed attack in varying degrees. Many specimens which had been cured at 100°F, with no color change, did show drastic changes at 950°F due to the action of sodium. The materials showing the least disintegration and greatest preservation of mechanical properties were Superex paste and Eagle-Picher mineral wool. The uncured Superex Block did not hold up as well as Superex paste, presumably due to the presence of water of crystallization; after curing, the results were similar to that of the paste. The refractory clays showed the greatest degree of destruction. The time element is of vital importance, since a long period of contact with liquid sodium would presumably result in complete destruction of every specimen tested. (auth)

NSA 13:11838

- 2.237 TID - 3544  
Sodium Reactivity Tests-Fiberfrax Insulation. Memo Report 79.  
W. Milich and E. C. King. Mar. 2, 1955. 3 p. (NP-7401)

NSA 13:11610

- 2.237 NP-5613  
PERFORMANCE TESTS OF THERMAL INSULATION FOR SODIUM PIPING.  
Memo Report No. 72. Walter Milich, R. C. Andrews, and E. C. King,  
Dec. 31, 1954. 9 p. Contract NObs-65426

Samples of Kaolin Wool, LK-61, Superex, Thermoflex RF-1400, and Unibestos No. 1200 were immersed in Na under an inert atmosphere at 350, 500, and 850°F for 16-minute periods. At 850°F Na penetrated and charred all of the insulations. Kaolin Wool and Thermoflex were the least effected at the lower temperatures. Samples of baked and unbaked LK-61, Superex, and Unibestos No. 1200 were tested for mechanical strength under wet and dry conditions. Unibestos proved to be the strongest of the insulations tested in either wet or dry conditions.

- 2.237 THE RADIATION INDUCED CORROSION OF BERYLLIUM OXIDE IN SODIUM  
AT 1500°F  
W. E. Brundage and W. W. Parkinson  
ORNL, Dec. 3, 1953, Decl. Dec. 6, 1959, 9 p. OTS,CF-53-12-42

Beryllium oxide specimens of various densities, immersed in sodium, were irradiated in the LITR for 328 hrs at 1500°F plus 110 hrs at 750°F. The exposure at the higher temperature was about  $1.8 \times 10^{19}$  thermal nvt and  $0.9 \times 10^{19}$  fast. Control specimens were subjected to the same heat treatment in sodium and the average weight loss was found to be 0.0007 g (0.037%) with no significant difference between the irradiated and control groups. The surface-to-volume ratio was roughly  $2.5 \text{ cm}^2/\text{cm}^3$ .

NSA 15:7701

- 2.237 KAPL-M-EEB-11  
Knolls Atomic Power Lab., Schenectady, N. Y.  
Evaluation of Norton Non-Metallic Bonded Boron Carbide Compacts  
Baldwin, E. E., G. L. Cutlar and F. W. Wiesinger  
October 28, 1954. 17 p. Contract W-31-109-Eng-52.

Physical and mechanical properties were determined, and simulated thermal service tests were run on boron carbide compacts bonded with several non-metallic binders. Non-metallic bonding of boron carbide for SIR shield cans offers no advantage over vibrating mix grade boron carbide, since the binders are not stable in Na and the properties of the compacts were no better than vibrating mix. NSA 10:10828

- 2.237 KAPL-M-EGB-14  
Resistance of Titanium Carbide Bearing Materials to Corrosion in Sodium. Brush, E. G., April 15, 1953. 6p.  
Contract W-31-109-Eng 52. Report No. 5 on Evaluation of the Behavior of Various Materials in Sodium (Problem No. 21)

The corrosion resistance of four titanium carbide ceramics was determined in Na at 500°C and was found to be of the same order of magnitude as Carboloy 55A and 779 (tungsten carbides).

NSA 10:10835

- 2.237 KAPL-M-LRM-2  
STATIC SODIUM CORROSION TESTS OF CERAMIC MATERIALS  
McCreight, L. R. (Knolls Atomic Power Lab., Schenectady, N. Y.)  
July 6, 1951. Contract W-31-109-Eng-52. 5p.

Static corrosion tests using aged and filtered sodium were run on 68 different specimens of nonmetallic material. All specimens were tested at 500°C for one month, then thirteen were selected for retesting at 750°C for another month. No definite correlation of corrosion rate and chemical composition between similar compositions was found. Data are tabulated. (P.C.H.)

- 2.237 KAPL-557  
Knolls Atomic Power Lab., Schenectady, N. Y.  
Summary Report of Reaction Tests of Various Materials Tested with Sodium and Sodium-Potassium Nelson, C.O.  
June 1, '51. Changed from Official Use Only June 26, 1956. 51 p.  
Contract W-31-109-Eng-52

Tabular data show the methods, conditions, and observations of tests carried out in air to determine the reactions of liquid Na and NaK with Al roofing, cloth (including protective clothing), laboratory equipment, fire-extinguishing materials, insulating and packing materials, oils paints, brass and Cu screens, and Li fire-extinguishing materials.

NSA 11:2251

- 2.237 TECHNICAL MEMORANDUM ON STABILITY OF CERAMIC MATERIALS IN LIQUID SODIUM AT TEMPERATURES UP TO 2000° F  
J. F. Collins, Fairchild Engine and Airplane Corp., Report No. IC-51-1-58 (Jan. 23, 1951).

- 2.237 Liquid-Metals Handbook. Richard N. Lyon, ed. June 1952.  
276 p. (NAVEXOS-P-733 (Rev.)). \$1.25 (GPO); Dep.

This second edition of the liquid-Metals Handbook incorporates suggested improvements and additional releasable data. It offers a reasonably complete compilation of information on liquid metals covering the physical properties, industrial utilization, corrosive effects on materials, heat transfer properties, heat transfer systems, heat transfer system components, and availability for production of low-melting-point alloys.

2.240 NaK SERVICE

2.240 THE EFFECT OF MOLTEN ALKALI METALS ON CONTAINMENT METALS AND ALLOYS AT HIGH TEMPERATURES

Amateau, M. F.

Defense Metals Information Center, Battelle Memorial Institute  
DMIC Report 169, May 28, 1962. 54 p.

Extensive review of literature on the effects of Na and NaK alloys, liquid Li and liquid and gaseous K, Rb and Cs on the corrosion and sliding and bearing properties of pure metals and alloys including stainless steel, superalloys and refractory metals. Topics include types of liquid-metal corrosion, factors affecting liquid-metal corrosion and techniques for investigating such. 71 ref. (R6m, 2-62; SGA-h, SS, EG-d37)

2.240 DUPLEX TUBE FOR SNAP-8 CORROSION LOOPS.

B. E. Farwell

7 May 1962. AGN-EDS-159. Aerojet-General Nucleonics,  
San Ramon, Calif.

This engineering data sheet covers 9Cr-1Mo steel tubing clad with Type 316 stainless steel for use in the SNAP-8 corrosion loops.

2.240 Liquid Metal Corrosion Research in the SNAP Dev. Program

Perlow, M. A. and Page, J. P., Atomics International

TID-7626 (Part 1), 1962

3rd Annual AEC-NASA Liquid Metals Corrosion Meeting

Corrosion studies of long life NaK loops using Type 316 stainless steel, Hastelloy N, Hastelloy C, and Haynes 25. Definite cases of intergranular attack were observed for Type 316 and Hastelloy N above 1200°F in NaK.

2.240 NAA-SR-6439, SNAP-2 Primary Coolant Development (July 19, 1961),  
Perlow, A.

The design, development, testing and selection of components integral to the primary coolant system for the SNAP-2 are described. Includes case hydraulic studies, heater development, corrosion studies (NaK), NaK hydride precipitation studies, lithium hydride shielding medium studies.

2.240 Liquid Metal Corrosion Research in SNAP (AI)

M. A. Perlow, J. R. Crosby, NASA TN-D-769, 1960.

Introduction to SNAP-2, SNAP-8, and SNAP-10 systems. NaK corrosion of containment materials is summarized.

NSA 15:13274

2.240 THE INVESTIGATION OF THE CORROSIVE ACTION OF NaK ALLOY ON METALS

Second Interim Report. J. W. Young, and E. C. Protter. (BW-ES-401-7) Contract NObs-34223.

2.240 AIRCRAFT NUCLEAR PROPULSION PROJECT QUARTERLY PROGRESS REPORT FOR PERIOD ENDING MAR. 10, 1956

June 13, 1956. Decl. with deletions Nov. 10, 1959. 225 p. (ORNL-2061) (Pts. I, II, and III). (Del.).

In materials research, a variety of tests involving NaK and materials of containment to 1500°F.

NSA 14:23757

2.240 See Also: 2.340, 3.440 and 4.400.

- 2.240 Corrosion Screening of Component Materials for NaK Heat Exchange Systems, Basham, S. J. et al. (BMI)  
Presented at Nuclear Engineering and Science Conf. held at Chicago Mar. 17 to 21, 1958. Preprint 24, Session 23, N. Y. AICE, 1958. 27 p.

Sixty-one materials which might be useful for special components, such as valve-seat inserts, valve plugs, shaft-seal facings, and bearings, in high-temperature NaK flow systems were screened in tilting-furnace corrosion experiments. These include high-temperature alloys, pure metals, cermets, and ceramics. The standard test consisted of confining a specimen to the hot end of a sealed Inconel X capsule partially filled with NaK and exposing the capsule for 110 hr (5000 cycles) in a tilting furnace. The hot end of the capsule was controlled at 1600 F. while the cold end was 2100 F. Post test corrosion evaluations were based on metallographic examinations, and specimen weight-change measurements capsule-wall examinations, and specimen surface-roughness changes. The materials were divided into three classes according to corrosion resistance: Class I (most promising) - attached to a depth of 1 mil or less; Class II (marginal) - attached to a depth of 1 to 4 mils; Class III (unsuitable) - attached to a depth greater than 4 mils. NSA 12:10593

- 2.240 AD 256511  
SODIUM AND SODIUM-POTASSIUM ALLOY FOR REACTOR COOLING AND STEAM GENERATION  
Trocki, T., Bruggeman, W. H. and Crever, F. E.  
Proc. Intern. Conf. Peaceful Uses Atomic Energy, Geneva, 1955, 9, 241-51 (Pub. 1956)

- 2.240 NP-5601  
PROGRESS REPORT NO. 27 FOR FEBRUARY AND MARCH 1955. J. W. Mauteller, ed. Apr. 22, 1955. 62p. Contract NObs-65426

Tests on the Mark B 3000-Kw steam generator are described, including a circulating cold trap and plugging indicator, system cleaning, pump performance, NaK furnace tube failure, boiler water analysis, and heat transfer. Engineering studies are summarized on vent and drain line closures, NaK cross flow exchanger, development of EM pumps, pressure gages, wetting with alkali liquid metals, thermal shock, bellows testing, valve cleaning and testing, and thermal insulation tests in liquid Na. The depression of Na<sub>2</sub>O solubility in Na by K is discussed. Further studies on inhibition of mass transfer of radioactive stainless steel constituents in Na are described. The removal of residual radioactive Na with Na flushes was studied. Further results on radioactive leak contamination and the reactions of molten Zr in water are reported.

- 2.240 NP - 5449  
Report No. 7, March 1, 1954 Thru May 7, 1954 to the Detroit Edison Company. J. R. Taylor, S. J. Rodgers, and H. J. Williams  
July 25, 1954. 37 p.

A 30-day test on Zr tubing produced a metallic deposit on a large portion of the outer or NaK contacting surface. The deposit was found to be very magnetic, and a chemical analysis showed that it was 75% Fe. The deposit formation was believed to have been caused by a form of mass-transfer due to the coexistence of a temperature differential and metals (type-316 stainless steel) having temperature-dependent solubilities in NaK. Weight and dimensional determinations made on the specimen tube before and after exposure showed no appreciable gain or loss of weight nor change in wall thickness. A metallurgical examination of the exposed Zr specimen the presence of black needle-like spider-web constituent which appeared to be at the grain boundaries penetrating to as much as half the thickness of the tube from the Na contacting side. This constituent was thought to be Zr hydrides. An examination by polarized light showed that recrystallization took place in all sections of the tube. A change in grain structure on the Na contacting surface was also evident with polarized light. An examination of the type-347 stainless steel IHX tube showed no erosion or corrosion and the tube structure was normal. An average concentration of 1.8 ppm of Zr at the sampling temperature was found in metal samples taken from the Na stream during the test. A total of less than 1 mg of Zr was found in Na and NaK cold traps analyzed at the conclusion of the tests, indicating that the amount of tube material lost to the liquid metals during the 30-day test was negligible.

- 2.240 CT-3726 Effect of Sodium-Potassium Alloy on Various Materials at Elevated Temperatures  
Kelman, LeRoy R.  
Argonne National Laboratory, Lemont, Illinois  
Contract W-31-109-Eng-38. Dec. 1, 1946 Decl. Dec. 20, 1955. 26p.

The corrosive effects of Na-K alloys were investigated at temperatures up to 800°C. Uranium, Th, Be, and Nb showed extremely good resistance to pure Na-K alloy. The presence of O in the Na-K alloy appeared to effect the corrosion resistance of these metals. Pure Fe and low carbon steels showed good resistance to Na-K alloys and appeared to be suitable metals for the construction of equipment to handle Na-K where structural strength and air corrosion resistance of elevated temperatures are not necessary. The presence of Cr and high-Cr alloys appeared to greatly accelerate the rate of attack of steel by Na-K alloy. Nickel and high-Ni alloys showed extremely good resistance to Na-K alloy. Type 302 stainless steel showed irregular corrosion when tested in Na-K alloy. In general, Cu and its alloys, C, Si, Ag, and Pt were found to be extensively attacked by Na-K.

- 2.240 1500°F Unstressed Corrosion, R. C. Andrews and E. C. King,  
April 30, 1953, 6 p (NP-4906; Memo Report 33) MSA

Tabular data are given on the corrosion of Ni-Zr alloys, 347 stainless steel, Inconel, Ni, and Mo in NaK for 500 hr at 1500°F.

- 2.240 CORROSION OF CERTAIN METALS BY POTASSIUM-SODIUM  
Preliminary Report 5. Oct. 1, 1947 (MSA). Appendix to Report NRL-C-3201, Dec. 9, 1947).
- 

2.241 Pure Metals

- 2.241 TID-5277(NAVEXOS-P-733)  
LIQUID METALS HANDBOOK: SODIUM-NaK SUPPLEMENT  
Carey B. Jackson, ed.-in-chief. June 1955  
445 p. \$2.00 (GPO); Dept.

This edition of the Liquid Metals Handbook (TID-5277; NAVEXOS-P-733) is devoted entirely to Na and NaK. Fifty authors have contributed material. Aspects of heat transfer treated include natural circulation, forced circulation, boiling, and condensation. System design and component chapters include thermal stress, piping considerations, thermal insulation, heat exchangers and steam generators, heating, and cooling. Applications of Na and NaK technology to the Genie project, the Mine Safety Appliances high-temperature system, and the Experimental Breeder Reactor are described. Includes corrosion data for metals, alloys, and ceramic materials.

- 2 241 See Also 3.440  
To be expanded in the supplement.
- 

2.242 Ferritic and Martensitic Steels

- 2.242 THE EFFECT OF MOLTEN ALKALI METALS ON CONTAINMENT METALS AND ALLOYS AT HIGH TEMPERATURES  
(DMIC-169)  
M. F. Amateau (BMI) May 28, 1962. 54p.

. . . refractory metals and ferritic stainless steels show good corrosion resistance in NaK to 1500°F. (More on abstract)

NSA 16:25714



- 2.242 NP-6051, Mine Safety Appliances Co., Callery, Penna.  
Corrosion of Low Alloy Steel in Hot NaK  
Memo Report 109. W. Milich and E. C. King, Mar. 30, 1956. 6 p.  
Contract NObs-65426.

Consideration is being given to the use of low alloy steels due to the difficulties encountered in the use of type 347 stainless steel for steam generating equipment. As a preliminary experiment, to check the corrosion of such steels by liquid metals, a type 304 stainless steel loop was revised to accommodate a section of 1 in. OD tubing composed of 2½% Cr--1% Mo steel. NaK (56 wt. % K) at 850°F was circulated at approximately 8 ft/sec. through this tubing for four months. Four small samples (½ in. weighed sections of the tubing) placed in an in-stream expansion tank were removed after 1, 2, 3, and 4 months immersion time and showed penetration of 0.19, 0.09, 0.07, and 0.06 mils/yr respectively. The section of test tubing showed no detectable weight loss after the 4 month period. With the temperature of the NaK at 850°F the oxygen content was found to be 0.032 wt. % O<sub>2</sub>. All results of the test run isothermally at 850°F indicated a rate of attack less than one mil per year. (auth) NSA 10-8373

2.242 HEAT EXCHANGERS AND STEAM GENERATORS

D. B. Nelson

The Reactor Handbook, Vol. 2, Engineering. Chapter 2.7, p. 337, 1955

Na and NaK to 950°F. Duplex tubes mentioned (in reference No. 3).

2.242 (NAVEXOS-P-733 (Rev.))

LIQUID-METALS HANDBOOK

Richard N. Lyon, ed. June 1952

276 p. \$1.25 (GPO); Dp.

This second edition of the Liquid-Metals Handbook incorporates suggested improvements and additional release data. It offers a reasonably complete compilation of information on liquid metals covering the physical properties, industrial utilization, corrosive effects on materials, heat transfer properties, heat transfer systems, heat transfer system components, and availability for production of low-melting point alloys.

2.242 Effect of Sodium-Potassium Alloy on Various Materials at Elevated Temperatures, LeRoy R. Kelman, Jan. 23, 1947, 26 p. (CT-3726)  
\$4.80(ph OTS); \$2.70(mf OTS). ANL

Tabular data are given on the corrosion of U, Th, Be, Nb, 1020 steel, Armco Fe, Ni, Zr-Ni, Invar, Inconel, Monel, 80% Ni-20% Mn, 17% Cr steel, 18-8 stainless steel, Cu, Al, bronze, Sn-bronze, 70% Cu-30% Mn, graphite, cast iron, Si, Ag, and Pt in Na-K alloy at 300° to 800°C.

---

2.243 Austenitic Steels and High Temperature Alloys

2.243 CORROSION OF STAINLESS STEEL TUBES BY LIQUID SODIUM SYSTEMS. I. THERMAL CONVECTIONAL CORROSION TESTING APPARATUS

Hideo Atsumo (Hitachi, Ltd., (Japan)). Nippon Gen-Shiryoki Gakkaishi, p. 94-9 (Feb. 1962) (In Japanese).

A new type thermal convection corrosion testing apparatus was set up to study liquid sodium corrosion of stainless steel. In order to investigate several factors simultaneously, thermal calculation and structure of the apparatus and welding methods of the test pieces in NaK circulating loops was examined. Long term corrosion testing of 18-8 stainless steel tubes by high temperature NaK was effected quite well by this method.

NSA 16:13538

- 2.243 HEAT TRANSFER THROUGH MOLTEN MATERIALS  
Inco Corrosion Reporter, v. 9, no. 2, Oct 1962, 13p.

Mechanism of liquid metal corrosion at high temperatures and under pressure in nuclear reactors as a function of solution rate and solubility limit of the solid metal in the liquid. Advantages and limitations of liquid metals as heat transfer media and use of 18-8 stainless steel with Na and NaK and Ni alloy Inor 8 with fluoride salt mixtures. 5 refs.

- 2.243 ORNL-2988  
METALS AND CERAMICS DIV. ANNUAL PROGRESS REPORT - 1960  
MATERIALS COMPATIBILITY  
E. E. Hoffman, W. H. Cook, et. al., ORNL-2988 (p. 221-43)

Studies to determine the compatibility of type 304 stainless steel and beryllium in a NaK environment were conducted at 1112, 1292, and 1472°K. A program to investigate the compatibility of boiling potassium with several potential container materials at 1600°F. Refluxing K capsule tests with metallographic and weight-change data is presented. A boiling-K-type 316 stainless steel loop test for 200 hrs at 1500°F resulted in no attack on the loop. An additional test was run for 1800 hours at 1600°F. Tests include the solubility of container materials in an alkali metal and the rate of solution of the container material. Thermal convection loop studies were being planned.

NSA 15:537

- 2.243 TRIAL MANUFACTURE OF AN EXPERIMENTAL NaK SYSTEM.  
Y. Imai, et al., (Tohoku Univ., Sendai). J. Atomic Energy Soc., Japan 2, 127-35 (1960) Mar. (In Japanese).

Static testing of NaK in stainless steel led to the system described. (More on the abstract.)

NSA 14:13830

- 2.243 Behavior of Type 347 Stainless Steel in Sodium Hydroxide at Elevated Temperatures. E. G. Brush. July 12, 1956.  
Includes attachment: Stress Corrosion Cracking of Steels in Caustic Solution. A Literature Survey. E. L. Brady and E. G. Brush, Sept. 10, 1956. Addendum: by E. G. Brush Sept. 14, 1956. 38 p. (KAPL-M\_EGB-22; KAPL-M-EGB-22 (add.))

Tests have been performed in various NaOH mixtures to investigate expected behavior of type 347 stainless steel in the S2G third fluid NaK filled system in the event of a water leak. Idealized capsule tests show stress corrosion cracking to be severe in 100% NaOH and in NaOH solutions containing appreciable amounts of water. Tests of NaOH plus various additives show, however, that if the corrosion rate can be made to exceed 5000 mg/dm<sup>2</sup> - Mo. the tendency to crack is reduced. The most promising additive seems to be NaH.

- 2.243 NP-6051, Mine Safety Appliances Co., Callery, Penna.  
Corrosion of Low Alloy Steel in Hot NaK  
Memo Report 109. W. Milich and E. C. King, Mar. 30, 1956. 6 p.

Consideration is being given to the use of low alloy steels due to the difficulties encountered in the use of type 347 stainless steel for steam generating equipment. As a preliminary experiment, to check the corrosion of such steels by liquid metals, a type 304 stainless steel loop was revised to accommodate a section of 1 in. OD tubing composed of 2½% Cr--1% Mo steel. NaK (56 wt. % K) at 850°F was circulated at approximately 8 ft/sec. through this tubing for four months. Four small samples (½ in. weighed sections of the tubing) placed in an in-stream expansion tank were removed after 1, 2, 3, and 4 months immersion time and showed penetration of 0.19, 0.09, 0.07, and 0.06 mills/yr respectively. The section of test tubing showed no detectable weight loss after the 4 month period. With the temperature of the NaK at 850°F the oxygen content was found to be 0.032 wt. % O<sub>2</sub>. All results of the test run isothermally at 850°F indicated a rate of attack less than one mil per year. (auth) NSA 10-8373

- 2.243 NP - 5921  
Progress Report No. 33 For February and March 1956. W. J. Posey, ed.  
Apr. 9, 1956. 57p. Contract NObs-65426

Progress is reported on the tests made on models of the S2G steam generators. Modifications of a 1000 KW test unit were made to permit adequate testing of the 3000 KW generators. The cyclic test program for the S2G is outlined. Typical Na flow data are given for the cyclic testing of the S2G evaporator. The operational history of this evaporator is also discussed. Progress is also reported on research pertaining to liquid metal system components, including fundamental heat transfer studies and component development and testing. Diagrams are given of the steam generators and tube joints. Operating characteristics of the liquid metal system are tabulated. The ability of transition welds to withstand the rapid temperature changes anticipated during scram conditions was studied. The suitability of stainless steel bellows for use in 8-in. S2G sodium valves was also studied. Results are given of 14 runs to determine the minimum velocity necessary to remove entrained gas by forcing it downward through the 5½-ft vertical leg for separation in the lower expansion tank. The nitriding of metals in Na is also discussed. The weight losses of Be specimens in 900°F Na are shown. A study was made of the characteristics of water-NaK leaks and applicable sealing methods. Data are given on the corrosion rate of Cr-Mo steel samples in NaK. It was found that the solubility of O in NaK is dependent on K concentration.

- 2.243 GENERATION OF STEAM FROM LIQUID AT HIGH HEAT FLUXES  
E. C. King and R. C. Andrews (Mine Safety Appliances Co., Callery, Pa.). Chem. Eng. Progr. Symposium Ser. 51, No. 17, 33-40 (1955).

The performance of specially designed double-wall stainless-steel tubes was compared with that of a single-wall tube in the generation of steam at high heat fluxes. Na-K alloy in the tubes was the heat-transfer medium. Heat was transferred at fluxes as high as 450,000 Btu/(hr.) (sq.ft.) at steam pressures between 113 and 1203 lb./sq.in. abs. The over-all heat-transfer coeffs. ranged from 412 to 1306 Btu/(hr.) (sq.ft.) (°F). Evaluation of the tube design and bond resistance was made and a method for calcg. the performance of such tubes is presented.

CA50-623i

- 2.243 TID-3305  
DISSOLUTION AND DISTRIBUTION BY LIQUID SODIUM OF ACTIVATED TYPE  
347 STAINLESS STEEL  
A. M. Saul, Mar. 15, 1954. Decl. Mar. 19, 1957. 26p. (TID-10021)

The distribution by Na of the radioactive elements of Type 347 stainless steel was studied under dynamic conditions using convection-diffusion capsules operating between 300 and 700°C. The nuclides identified as depositing on the initially inactive walls of these capsules are Ta<sup>182</sup>, Fe<sup>59</sup>, Co<sup>60</sup>, Cr<sup>51</sup>, and Mn<sup>54</sup>. Deposition of these activities does not seem to be a function of capsule wall temperature alone. It was found that the presence of O<sub>2</sub> greatly accelerates the transfer of activity.

- 2.243 KAPL - M - WLF - 5  
Examination of the Natural Circulation Steam Generator From the  
Liquid Metal Heat Transfer Test Facility at Alplaus, N. Y.  
Callahan, E. J. and W. L. Fleischmann  
KAPL-M-WLF-5 September 12, 1953. Changed from Official Use Only  
Oct. 8, 1956, 35 p. Problem No. 70: Investigation of the  
Causes of Cracking in the Natural Circulation. Contract  
W-31-109-Eng-52

The first structural failure of a heat exchanger in the Alplaus liquid metal system is discussed. The metallurgical examination revealed failure of two Type 347 stainless steel tubes (NaK outside, mercury inside) and two tube sheets. The location of the failure was confined to the hot end and the area around these two hottest tubes. Judging by the fracture appearance, the majority of the cracks were caused by thermal cycling. Further studies are under way to establish more definitely the cause of the failure.  
NSA 11:3791

- 2.243 NAA-SR-74 (Del.)  
Epp, A. A. et al. (North American Aviation, Inc., Downey, Calif.)  
Cyclotron Irradiation of Type 347 Stainless Steel Welds in NaK  
at Elevated Temperatures. Jan. 7, 1953. Decl. with deletions April  
11, 1957. Contract AT-11-1-GEN-8. 42 pages.

Capsules of type 347 stainless steel, containing samples of arc welded 347 immersed in NaK of 78 weight-per cent K, were irradiated with deuterons on the 60 inch cyclotron at Berkeley while maintained near 450°C. Power densities ranging from 2500 to 5000 watts/cm<sup>3</sup> were achieved in the weld samples near the NaK interface. The irradiations were between 10 and 20 hours in length, at average beam currents from 1.5 to 3 micro-amperes. Control runs in which the capsules were heated, but not irradiated, and in which a weld sample was irradiated in an evacuated capsule, were also made. No conclusive evidence was obtained that weld corrosion was accelerated in the irradiated runs, compared with unirradiated controls. In addition to weighing the samples, examining them metallographically for evidence of corrosion and analyzing the NaK chemically after the runs, observations were also made of surface hardness, grain size and x-ray-diffraction patterns of the weld samples. No significant differences were found between the irradiated and control samples.

NSA 12:8421

- 2.243 KAPL-M-EGB-4  
ALPLAUS SURVEILLANCE PROGRAM. Progress Report No. 2. E. G. Brush  
Aug. 29, 1952. Changed from Official Use Only June 26, 1956. 9 p.

Type-347 stainless steel and L nickel, considered as construction materials in the Alplaus heat-transfer system, were placed in the system to determine their corrosion resistance to liquid Na and NaK. The specimens were very resistant to attack by Na at 950°F and NaK at 850°F. There was no evidence of mass transfer between the stainless steel and Ni specimens. No transfer of mass from the hot to the cold zones occurred in one year.

- 2.243 KAPL-M-JEZ-1  
RECENT DEVELOPMENTS ON THE STANDBY COOLANT SYSTEM FOR THE WEST  
MILTON REACTOR. John E. Zerbe. June 20, 1949. Decl. Mar. 27, 1957.  
12p.

The work done previously on the Standby Coolant System was reviewed in the light of more recent reactor designs and heat transfer data. It has been found that if a NaK-Na heat exchanger consisting of 16-1½" OD 60 mil wall stainless steel tubes is used, the thermal stress is reduced to approximately 22,000 psi when 2½% of 30 Mw is transferred under steady state conditions. Further calculations based on dissipating 2½% of 30 Mw have shown that the thermal stress is not influenced noticeably by the temperature rise in the NaK system. This is for both 80-20 (eutectic) NaK and 50-50 NaK. However, assuming the NaK-air exchanger is placed at a height of 55 feet the factor of safety for the various temperature rises in the NaK loops is different. Thus, for 80-20 NaK, if  $\Delta T_{NaK}$  equals 200°F, calculations show that the exchanger must be at least 40 feet in the stack; for  $\Delta T_{NaK} = 150^\circ$  the exchanger must be located at about 86 feet. If 50-50 NaK were used, the factor of safety would be greater than with 80-20 NaK.

---

2.244 Nickel and Cobalt Base Alloys

- 2.244 HEAT TRANSFER THROUGH MOLTEN MATERIALS  
Inco Corrosion Reporter, v. 9, no. 2, Oct 1962, 13p.

Mechanism of liquid metal corrosion at high temperatures and under pressure in nuclear reactors as a function of solution rate and solubility limit of the solid metal in the liquid. Advantages and limitations of liquid metals as heat transfer media and use of 18-8 stainless steel with Na and NaK and Ni alloy Inor 8 with fluoride salt mixtures. 5 refs.

- 2.244 TID-7626 (Part 1) 1962  
LIQUID METAL CORROSION RESEARCH IN THE SNAP DEVELOPMENT PROGRAM  
Perlow, M. A. and Page, J. P., Atomics International  
3rd Annual AEC-NASA Liquid Metals Corrosion Meeting, 1962

Corrosion studies of long life NaK loops using Type 316 stainless steel, Hastelloy N, Hastelloy C, and Haynes 25. Definite cases of intergranular attack were observed for Type 316 and Hastelloy N above 1200°F in NaK.

- 2.244 PWAC-592 (Secret)  
Pratt and Whitney Aircraft Division, United Aircraft Corporation,  
Middletown, Connecticut.  
Nuclear Propulsion Program Engineering Progress Report For April 1, 1959 - June 30, 1959. July, 1959. 124 p.

...Haynes 25 ... with NaK to determine the corrosion ...

- 2.244 BMI-1191 (Secret)  
Battelle Memorial Institute, Columbus, Ohio.  
Pumping-Loop Corrosion Studies of Fused-Salt-Reactor Structural Materials.  
J. H. Stang and J. F. Lagedrost. June, 1957. 60 p.

... in a minor part of the work, the behavior of ... Hastelloy X, exposed to ... NaK was examined ... RL

- 2.244 ORNL-2422, (Secret), Oak Ridge National Laboratory, Tennessee.  
Metallurgy Division Annual Progress Report For Period Ending October 10, 1957. December, 1957. 247 p.

... Inconel-Na and Inconel-NaK ... ACR 14:425

- 2.244 ORNL 2422(Del) -Declass. from the above  
Metallurgy Division Annual Progress Report for Period Ending Oct. 10, 1957. Dec. 13, 1957. Decl. with deletions Oct. 29, 1959. 147p. Contract W-7405-eng-26. OTS.

Na and NaK pumped Inconel loops. Studies include corrosion, mass transfer, H<sub>2</sub> embrittlement, and purification. NSA 14:1763

- 2.244 KAPL-M-EGB-4  
ALPLAUS SURVEILLANCE PROGRAM. Progress Report No. 2. E. G. Brush  
Aug. 29, 1952. Changed from Official Use Only June 26, 1956. 9 p.

Type-347 stainless steel and L nickel, considered as construction materials in the Alplaus heat-transfer system, were placed in the system to determine their corrosion resistance to liquid Na and NaK. The specimens were very resistant to attack by Na at 950°F and NaK at 850°F. There was no evidence of mass transfer between the stainless steel and Ni specimens. No transfer of mass from the hot to the cold zones occurred in one year.

- 2.244 See Also 2.234 & 2.440
-

2.245      Refractory Metals

2.245      THE EFFECT OF MOLTEN ALKALI METALS ON CONTAINMENT METALS AND ALLOYS AT HIGH TEMPERATURES  
(DMIC-169)

M. F. Amateau (BMI) May 28, 1962. 54p.

. . . refractory metals and ferritic stainless steels show good corrosion resistance in NaK to 1500°F. (More on abstract)

NSA 16:25714

2.245      The Embrittlement of Nb in H<sub>2</sub> Contaminated NaK,  
A. Thorley, E. C. Tyzack (Reactor Materials Lab, Culcheth, Eng.)  
Preprint SM 26/49, 34 p. (To be printed in the Proceedings of  
IAEA Symposium on Thermodynamics of Nuclear Materials, held in  
Vienna, 21-25 March 62).

A study was made of uptake and equilibrium levels of H<sub>2</sub> attained by Nb specimens exposed to dynamic NaK (70% K) alloy circulated in an electro-magnetic pumped circuit at 350°C.... The extent of embrittlement of Nb at various H<sub>2</sub> levels was also evaluated by mechanical tests.

NSA 16:25402

2.245      TID-7622  
IMPURITIES IN A LIQUID METAL COOLANT AND THEIR EFFECT ON THE FUEL ELEMENT CANNING MATERIALS NIOBIUM AND VANADIUM

Sinclair, V. M., Pool, R. A. H. and Ross, A. E.

Nuclear Reactor Chemistry (Second Conference, Gatlinburg, Tenn.

July 1962. pp 35-56

Review of the properties of H<sub>2</sub>, N<sub>2</sub>, O<sub>2</sub>, and C in the primary coolant (70% Na-30% K) and effects of these nonmetallic impurities on the Cb and V fuel cans from 200°C to 800°C. 16 refs.

2.245      NIOBIUM-PROMISING, HIGH-TEMPERATURE REACTOR-CORE MATERIAL

J. A. DeMastery and R. F. Dickerson (BMI)

Nucleonics 18, No. 9, 87-90; 132; 134 (1960) Sept.

Physical properties of Cb as they are affected by oxygen. Corrosion tests of Cb in NaK.

NSA 14:23350

2.245      BMI-1400  
Metallurgical Studies of Niobium-Uranium Alloys.

J. A. DeMastry, F. R. Shober, and R. F. Dickenson (BMI)

Dec. 7, 1959. 44 p. Contract W-7405-Eng.-92 OB

All of the alloys appear compatible with NaK at 1600°F. The impurity combinations, of oxygen and zirconium, employed in the base niobium appeared to have no effect on the corrosion behavior and mechanical properties of the alloys.

NSA 14:4500

2.245      Selection of Canning Materials for Reactors Cooled by Sodium/Potassium and Carbon Dioxide.

McIntosh, A. B. and K. Q. Bagley

U. S. Atomic Energy Authority (Industrial Group), Calcheth, Lancs. England). J. Inst. Metals 84, 250-70 (1956). March.

Theoretical considerations and experimental investigations indicate such metals as beryllium, zirconium, niobium, vanadium, tungsten, and molybdenum will be used for canning materials provided difficulties in extraction and fabrications can be overcome.

- 2.245 IGR-TN/W-597, Unclassified, United Kingdom Atomic Energy Authority. Industrial Group. Windscale Works, Sellafield, Cumb., England  
Corrosion of Niobium and Vanadium in NaK Circuits; An Interim Report of Work at R and D.B. Windscale up to June 15, 1957.  
Draycott, A., Aug. 1957. 18p.

The results of some preliminary experiments in the compatibility studies of niobium and of vanadium in NaK circuits are reported. With normal cold trapping, corrosion of both these materials in a NaK circuit under Fast Reactor conditions is extremely high but can be reduced by incorporating in the circuit, elements with greater affinity for oxygen than the subject metals. This may be achieved by elements that are soluble in the liquid metal and react preferentially with any sodium oxide present. or by insoluble elements that show preferential oxidation at elevated temperatures. Results with the use of magnesium and barium are reported in the first group, and with zirconium, by means of a hot trap, in the second group. Because of the greater ease of control, more consideration has been given to hot trapping, but preliminary cleaning by cold trapping is still imperative. Detailed recommendations are made of the method for effecting this cold-trapping hot-trapping technique in the operation and maintenance of the Fast Reactor Circuit. (auth) TID-1181 No. 14-15 1337-1510

- 2.245 See Also: 2.235, 2.241, and 3.440

---

2.246 Other Nonferrous Metals

- 2.246 AN APPARATUS FOR OBSERVING CRACKING AND CREEP IN ZIRCONIUM ALLOY SPECIMENS WHEN IMMERSSED IN MOLTEN Na or NaK  
(NAA-SR-Memo-5261)  
D. M. Lonneaux (AI) May 6, 1960. 4p. OTS.

A study was made of vessel designs to test zirconium alloy specimens under tensile stresses sufficient to produce 2% elongation while immersed in molten alkali metals and to externally measure the creep of the specimens.

NSA 15:6202

- 2.246 The Compatibility of Beryllium with Liquid Sodium and NaK in Dynamic Systems  
Bett, F. L. and Draycott, A. (Australia) 16 p.  
A/CONF. 15/P/1091, Geneva, 1958, v7, p125 .

The mechanism of corrosion of beryllium in oxygen-bearing sodium and NaK is briefly discussed. Experiments are described which measure the rate of corrosion of beryllium in cold-trapped NaK. These corrosion rates are found to be excessive. As oxygen in the liquid metal is considered to be the cause of the corrosion, cold trapping is supplemented by hot trapping as a means of deoxidation of NaK in a second series of experiments. These experiments show that with a thorium hot-trap reduced corrosion of beryllium occurs compared with cold-trap conditions, but is still excessive. Calcium, however, when used in the hot-trap reduces beryllium corrosion to an acceptable level. At the levels required for successful hot-trapping calcium removes negligible quantities of nickel from stainless steel which can therefore be used as a container material.

NSA 13:6787

- 2.246 See Also: 2.241, 2.236, and 3.440.

- 2.246 IGR-TN/W-597, Unclassified, United Kingdom Atomic Energy Authority. Industrial Group. Windscale Works, Sellafield, Cumb., England  
Corrosion of Niobium and Vanadium in NaK Circuits; An Interim Report of Work at R and D.B. Windscale up to June 15, 1957.  
Draycott, A., Aug. 1957. 18p.

The results of some preliminary experiments in the compatibility studies of niobium and of vanadium in NaK circuits are reported. With normal cold trapping, corrosion of both these materials in a NaK circuit under Fast Reactor conditions is extremely high but can be reduced by incorporating in the circuit, elements with greater affinity for oxygen than the subject metals. This may be achieved by elements that are soluble in the liquid metal and react preferentially with any sodium oxide present. or by insoluble elements that show preferential oxidation at elevated temperatures. Results with the use of magnesium and barium are reported in the first group, and with zirconium, by means of a hot trap, in the second group. Because of the greater ease of control, more consideration has been given to hot trapping, but preliminary cleaning by cold trapping is still imperative. Detailed recommendations are made of the method for effecting this cold-trapping hot-trapping technique in the operation and maintenance of the Fast Reactor Circuit. (auth) TID-1181 No. 14-15  
1337-1510

- 2.246 KAPL-M-WW-2 Thermal Stress in a Beryllium Washer  
Witzig, Warren F. and William A. Riemen  
Knolls Atomic Power Lab., Schenectady, N. Y.  
Contract W-31-109-Eng-52. July 1, 1949. Dec. Feb. 8, 1956. 17p.

Thermal stress was produced by a large radial heat flux in a Be washer immersed in a NaK alloy. After 7,000 cycles of thermal stress, the washer maintained its principle dimensions, but developed small radial cracks. There was a 2 mg. wt. gain despite obvious corrosion.

- 2.246 ANL-5090  
Corrosion of Plutonium Alloys in NaK  
Hyman, H. H. and Katz, J. J.  
ANL-5090, July 1953, Decl. March 15, 1960  
Contract W-31-109-Eng-38

A Pu-Al alloy containing 4 at. % Al showed no attack after exposure to purified NaK for one month at 400°C in the absence of any oxide. The same specimen and other Pu alloys, including pure Pu, showed marked deterioration in shorter exposures in the presence of oxide films from a welded stainless steel container. Pure U was found to be resistant in the presence of such oxides.

NSA 14:11922

- 2.246 Resistance of Materials to Attack by NAK.  
L. R. Kelman, P. G. Drugas. Unpublished data reported in ANL Met. Div. Quarterly Progress Reports for Period Jan. 1947 through June 1948, Reports: CT-3802, ANL-4003, ANL-4069; ANL-4103, ANL-4150, ANL-4188

Film formation on Zirconium exposed to NAK.



2.247      Nonmetallic Materials

- 2.247    TID 14979    GLASS FABRIC SWATCH TEST ON Na AND NaK FUMES FOR  
ATOMICS INTERNATIONAL, American Air Filter Co.,  
Louisville, June 9, 1961.

Tests were made on the feasibility of using a glass bag cloth collector for removing Na and NaK fumes.

NSA 16:12660

- 2.247    COMPATIBILITY OF MATERIALS IN LIQUID METAL AND COMPOSITION 30  
(TID-12268)  
H. P. Leeper (Pratt & Whitney Aircraft Div.) Mar 1956, Decl.  
Sept 18, 1959 (TIM-251)

Compatibility tests of various material combinations under conditions of static or rubbing contact in 1500°F NaK. (More on abstract)

NSA 15:14661

- 2.247    KAPL-557  
Knolls Atomic Power Lab., Schenectady, N. Y.  
Summary Report of Reaction Tests of Various Materials Tested with  
Sodium and Sodium-Potassium    Nelson, C.O.  
June 1, '51. Changed from Official Use Only June 26, 1956. 51 p.  
Contract W-31-109-Eng-52

Tabular data show the methods, conditions, and observations of tests carried out in air to determine the reactions of liquid Na and NaK with Al roofing, cloth (including protective clothing), laboratory equipment, fire-extinguishing materials, insulating and packing materials, oils paints, brass and Cu screens, and Li fire-extinguishing materials.

NSA 11:2251

- 2.247    KAPL-M-LRM 2  
Static Sodium Corrosion Tests of Ceramic Materials  
L. R. McCreight,    July 6, 1951

Static corrosion testing using aged and filtered Na were run on 68 different specimens of non-metallic materials. All specimens were tested at 500°C for 1 month then 13 selected for retest at 750°C for 1 more month. No definite correlation of corrosion rate and chemical compound between similar compositions was found. Data are tabulated.

NSA 16:29340

- 2.247    See Also    2.237    &    3.440
-

## 2.300 BNL-756

DEVELOPMENT PROBLEMS OF SNAP REACTOR SYSTEMS

G. M. Anderson, Atomic Energy Comm., Div. Reactor Development  
Second Annual High Temperature Liquid Metal Heat Transfer Meeting,  
Brookhaven Nat. Laboratory, May 17, 1962

A review of major problem areas in the hardware development of current SNAP systems. The temperature vs endurance life relationships are covered, primarily from the reactor performance aspect. Space environment aspects of both dynamic conversion and direct conversion power systems are included. NaK and mercury loop components are mentioned.

## 2.300 TID-7626 (Part 1)

Summary of Work at Aerojet-General Nucleonics on Liquid Metal Corrosion (NASA-AEC Liquid Metals Corrosion Meeting, Dec. 1961 at BNL)

Six liquid metal programs reviewed.  
(AGN Lib. 2-2786)

2.300 AD258462 LIQUID METAL COOLANTS IN NUCLEAR REACTORS  
(ATIC WADD) (TRANS.)

Information (based on foreign sources) on properties of liquid metals used as coolants in reactors is presented. Topics include: 1) heat transfer 2) interaction of liquid metals with structural materials 3) methods for removing impurities from liquid metals 4) peculiarities of design and operation ....

2.300 TID -7623, PROCEEDINGS OF SYMPOSIUM ON Na REACTORS TECH  
May 24-25, 1961.

The history and present status of liquid metal cooled reactors particularly Na are discussed. Compares the several properties of gas, liquid, the liquid metals.  
NSA 16:28545

2.300 HIGH-TEMPERATURE CORROSION BY COOLANTS (BNL)  
D. H. Gurninsky and C. J. Klamut, NASA TN D-769, 1960

Na and Hg corrosion, Zr inhibitors, solubility studies, and a variety of capsule and loop tests.

2.300 STATUS REPORT FOR SODIUM GRAPHITE REACTORS  
(A.I.) NAA-SR-Memo-4156. July 1959. 110 p. OTS.

Reactors discussed include SRE, SCRE, HNPF, SIR, and the 300 Mw Canned Moderator Reactor.

NSA 14:4128

2.300 FINAL REPORT (FROM MSA) FOR WORK DONE ON CONTRACT Nobs-65426  
Mar. 20, 1959. 73 p. (MSAR-59-29)

A brief general review of the work accomplished during the 5 year life of the contract, Dec. 1953 to Dec. 1958. This report includes research and development work on liquid metals.

NSA 13: 12088

2.300 See Also: 2.200, 2.350, 2.400, 5.300, and 5.400.

- 2.300 FERMI AND HALLUM STEAM GENERATORS  
F. Boni and P. S. Otten (Griscom-Russell Co., Masillon, Ohio).  
Nucleonics, 19; No. 6, 58-61 (June 1961).

Design characteristics of the heat exchangers used in the Fermi Fast Breeder Power Reactor and the Hallam Power Reactor are outlined. Particular attention is devoted to thermal stress reduction and leak handling measures, and the materials used in the steam generators of the two reactors are described. (T.F.H.)

NSA 15: 19523

- 2.300 AIRCRAFT NUCLEAR PROPULSION PROJECT QUARTERLY PROGRESS REPORT FOR PERIOD ENDING JUNE 10, 1956  
A. W. Sarolaninen, ed. Sept. 4, 1956. Decl. with deletions Dec. 2, 1959. 257 p. Contract W-7405-eng-26. OTS. ORNL-2106 (Pts. 1-5) (Del.)

Progress reported on physical properties of molten materials, compatibility of materials at high temperatures, dynamic corrosion studies, and general-corrosion studies.

NSA 15:1110

- 2.300 METALLURGY DIVISION SEMIANNUAL PROGRESS REPORT FOR PERIOD ENDING APRIL 10, 1956  
ORNL-2080 (Del) Nov. 2, 1956. Decl. with deletions Nov. 13, 1959. 209 p. Contract W-7405-eng-26. OTS.

Material compatibility in liquid metals ...

NSA 14:24488

- 2.300 NUCLEAR ENGINEERING PROGRAM  
Topical Report No. 1, July 1, 1955 - June 30, 1956. (Pratt and Whitney Aircraft Div., United Aircraft Corp., Hartford, Conn.)  
Contracts AF33(038)-27341 and AT(11-1)-229p. 82 p. Fox Project.  
Includes Na and NaK.

NSA 17:7565

- 2.300 AIRCRAFT NUCLEAR PROPULSION PROJECT QUARTERLY PROGRESS REPORT FOR PERIOD ENDING SEPTEMBER 10, 1955  
ORNL-1947 (Del.)  
A. W. Savolainen, ed. Nov. 10, 1955. Decl. with deletions Oct. 22, 1959. 175 p. Contract W-7405-eng-26. OTS.

NSA 14:16457

- 2.300 AIRCRAFT NUCLEAR PROPULSION PROJECT QUARTERLY PROGRESS REPORT FOR PERIOD ENDING JUNE 10, 1955  
A. W. Savolainen, ed. July 28, 1955. Decl. with deletions Nov. 13, 1959. 179 p. OTS. ORNL-1896 (Del.)

NSA 15:1109

- 2.300 AIRCRAFT NUCLEAR PROPULSION PROJECT QUARTERLY PROGRESS REPORT FOR PERIOD ENDING SEPTEMBER 10, 1954  
ORNL-1771 (Del.)  
A. W. Savolainen, ed. Oct. 29, 1954. Decl. with deletions Dec. 2, 1959. 152 p. Contract W-7405-eng-26. OTS.

Progress is reported on the chemistry of molten materials, corrosion research, metallurgy, heat transfer, physical properties, radiation damage, and analytical studies of reactor materials.

NSA 15:1108

- 2.300 AIRCRAFT NUCLEAR PROPULSION PROJECT QUARTERLY PROGRESS REPORT FOR PERIOD ENDING MARCH 10, 1953.  
W. B. Cottrell, ed. (ORNL-1515 (del.)) April 16, 1953. Decl. with deletions Dec. 14, 1959, 147 p. Contract W-7405-eng-26. OTS  
NSA 15:5856
- 2.300 AIRCRAFT NUCLEAR PROPULSION PROJECT QUARTERLY PROGRESS REPORT FOR PERIOD ENDING MARCH 10, 1953.  
W. B. Cottrell ed. (ORNL) Apr. 16, 1953 Contract W-7405-eng-26. 179 p. (ORNL-1515)  
NSA 17:7606
- 2.300 AIRCRAFT NUCLEAR PROPULSION PROJECT QUARTERLY PROGRESS REPORT FOR PERIOD ENDING DECEMBER 10, 1952  
W. B. Cottrell, ed. Decl. with deletions Nov. 16, 1959. 156 p. Contract W-7405-eng-26. OTS. (ORNL-1439 (Del.)).  
NSA 14:18645
- 2.300 AIRCRAFT NUCLEAR PROPULSION PROJECT QUARTERLY PROGRESS REPORT FOR PERIOD ENDING SEPTEMBER 10, 1952  
W. B. Cottrell, ed. Nov. 19, 1955. Decl. with deletions Nov. 16, 1959. 146 p. Contract W-7405-eng-26. OTS. ORNL-1375 (Del.)  
Includes liquid metal corrosion.  
NSA 14:23838
- 2.300 AIRCRAFT NUCLEAR PROPULSION PROJECT QUARTERLY PROGRESS REPORT FOR PERIOD ENDING DECEMBER 10, 1951  
(ORNL-1170 (Del.))  
W. B. Cottrell, ed. March 6, 1952. Decl. with deletions Oct. 27, 1959. 141 p. Contract W-7405-eng-26. OTS.  
NSA 14:15488
- 2.300 AIRCRAFT NUCLEAR PROPULSION PROJECT QUARTERLY PROGRESS REPORT FOR PERIOD ENDING MARCH 10, 1951  
W. B. Cottrell, ed. June 19, 1951. Decl. with deletions Jan. 7, 1960. 262 p. Contract W-7405-eng-26. OTS. ORNL, ANP-60 (Del.)  
Chemistry of liquid fuels, corrosion experimentation, liquid metal and heat transfer research, components of liquid metal systems, and metallurgical processes are reported.  
NSA 15:1105
- 2.300 STATUS REPORT VII  
C. B. Jackson, R. C. Werner  
Contract N9-ONL-85801.
- 2.300 RESISTANCE OF MATERIALS TO ATTACK BY LIQUID METALS  
Kelman, L. K., W. D. Wilkinson, (ANL-4417) July 1950.
-

- 2.310 SNAP-8 QUARTERLY PROGRESS REPORT FOR PERIOD 24 AUGUST TO 23 NOVEMBER 1962  
 AN-787. December 1962  
 P. F. Young, Aerojet-General Nucleonics, San Ramon, California

This report discusses the analytical and experimental work performed in support of the basic materials research for the SNAP-8 program. This work includes corrosion compatibility in mono- and bi-metallic capsules and advanced thermal convection capsules; studies of the solubility of certain elements in Hg; nuclear coordination of the irradiation of SNAP-8 materials and components; and some pool boiling heat transfer experiments to determine the effects of additives on the wetting of materials by Hg. Results of these investigations are reported.

- 2.310 SNAP-8 QUARTERLY PROGRESS REPORT (FOR) PERIOD JUNE 1, 1962 TO AUGUST 31, 1962  
 AN-721. Sept. 1962  
 J. R. Payne, Aerojet-General Nucleonics, San Ramon, Calif.

This report discusses the analytical and experimental work connected with the development of a mercury boiler, condenser radiator, and basic materials research for the SNAP-8 program.

- 2.310 SNAP-8 MATERIALS TASK GROUP REPORT, AD-HOC COMMITTEE REPORT  
 L. Rosenblum, NASA (Chairman)  
 Pub. by Aerojet General Corporation, Azusa  
 August 20, 1962

Review of critical problem areas relative to long life mercury and NaK systems. The neglected development of the NaK system and the poor corrosion resistance of the Haynes 25 alloy in mercury were discussed.

- 2.310 MERCURY CORROSION LOOP TESTING PROGRAM QUARTERLY REPORT FOR PERIOD 1 JANUARY THROUGH 31 MARCH 1962  
 (Report No. 0584-04-2. 27 April 1962, Power/Equipment Division, Aerojet-General Corporation, Azusa, Calif. NAS 3-1925.)

The Mercury Corrosion Loop Testing Program continued through the second quarter. Materials to be tested in the 10 forced-convection test loops were selected; the materials are: Haynes 25, 9 Cr-1Mo alloy clad with Type 316 stainless steel, AM 350 stainless steel, and columbium (niobium) clad with Type 316 stainless steel. The eight test-cell facility was completed and all utilities were installed. Pneumatic and electronic instrumentation for all test cells was installed and calibrated. Fabrication was initiated on the first four Haynes 25 loops. The first loop was 85% assembled at the end of the quarter. A centrifugal pump made from Type 316 stainless steel was tested; bearing modifications were made to improve operation.

- 2.310 MERCURY CORROSION LOOP TESTING PROGRAM QUARTERLY PROGRESS REPORT FOR PERIOD 1 JULY TO 30 SEPTEMBER 1962  
 (AN-744) Contract OP-328862  
 J. R. Payne, Aerojet-General Nucleonics, San Ramon, Calif.,  
 October 1962

This report describes the fabrication, testing and analysis work accomplished during the fourth quarter (July - September 1962) of the Dynamic Mercury Corrosion Loop Testing Program. Operation and modification of the first of the ten loops were continued. Some of the special alloys to be used in the later loops were received.

- 2.310 MERCURY CORROSION LOOP TESTING PROGRAM QUARTERLY PROGRESS REPORT FOR PERIOD APRIL 1 TO JUNE 30, 1962.  
(MCLP-11) Contract OP-328862  
J. R. Payne, Aerojet-General Nucleonics, San Ramon, Calif.  
July 1962

This report describes the fabrication and testing accomplished during the third quarter (April - June 1962) of the Dynamic Mercury Corrosion Loop Testing Program. Operation of the first of ten loops which are to be tested was begun, a second loop was fabricated, and tubing made of special alloys was procured for the fabrication of further loops.

- 2.310 CNEN Program For a Mercury Binary Cycle Nuclear Power Plant. Aldo Forcella ( CNEN, Italy) Preprint Paper No. 14. NY Engineers Joint Council 1962 18p.

A program leading to construction of a prototype plant consisting of a Na-cooled fast reactor system in which the heat generated in the primary Na is used to raise the Hg vapor in a Na-Hg boiler is described. This vapor is then expanded in a turbo-generator set where part of reactor heat is converted to electricity. The exhaust Hg steam flows thru a condenser-H<sub>2</sub>O boiler where remaining heat energy is utilized to generate water steam which is then fed to another turbo generator thru a conventional steam cycle. Discussions of Hg plant equipment thermodynamics and economic considerations are included.

NSA 16:31303

- 2.310 Vapor-Liquid Corrosion Studies in Mercury and Sodium Systems  
A. Fleitman, A. Romano, and C. Klamat (BNL) (NASA-AEC Liquid Metal Corrosion Meeting Dec. 1961 at BNL)

Corrosive behavior of liquid Hg and Hg vapor from 600-1400°F, and of liquid Na and Na vapor from 1500-2400°F. Refractory metals including Cb-12r alloy are under investigation in loops and capsules. Wetting and inhibitors tested. TID-7626 (Part 1) (AGN Lib. 2-2786)

- 2.310 Liquid Metal Research  
NASA-Lewis (NASA-AEC Liquid Metals Corrosion Meeting, Dec. 1961 at BNL)

Hg corrosion loops and capsules; includes solubility study.  
TID-7626 (Part 1) (AGN Lib. 2-2786)

- 2.310 AGC-0584-04-1 Mercury Corrosion Loop Testing Program  
First Quarterly (Progress Report),  
September 21 - December 31, 1961  
(Aerojet General Corp., Azusa, Calif.)  
Mar. 1962. Contract NAS-3-1925.  
For National Aeronautics and Space  
Administration, Washington, D. C. 10 p.

The design of the corrosion loops was completed and drawings were released for use in fabrication. Fabrication of loop components and instrument procurement was initiated. The test facility was designed and the test cells were erected. Installation of the test cell exhaust system is nearly complete, and installation of electrical components is in progress. (J.R.D.)

- 2.310 NAA-SR-6306  
THE SNAP II POWER CONVERSION SYSTEM - TOPICAL REPORT NO. 14.  
MERCURY MATERIAL EVALUATION AND SELECTION. TAPCO ER-4461  
J. F. Nejedlik, April 10, 1961. Prepared under Subcontract  
N843FS-101221 for A.I.

The SNAP II System consists of a reactor heat source, a boiler a mercury Rankine engine, an alternator, and a condenser. The corrosion and subsequent mass transfer resulting from the use of mercury as the thermodynamic working fluid have been under study for the past three years. This report presents the recent results of this study and discusses the corrosion mechanisms involved. (AGN Lib. 2-6456)

- 2.310 NASA TN-D-1188  
SUMMARY OF MERCURY CONDENSING WORK. Presented at the Government Industry Conference on Mercury Condensing. April 18, 1961.  
J. Neustein and L. Hays, Electro-Optical Systems Inc.

The compound loop which is used for both direct and indirect condenser investigations is described, components discussed, and results tabulated.

- 2.310 NASA TN-D-1188  
AERONAUTICAL SYSTEMS DIVISION PROGRAMS IN MERCURY CONDENSING  
Presented at the Government - Industry Conference on Mercury Condensing. April 18, 1961. Lt. Lloyd M. Hedgepeth

The programs briefly discussed are: Solar Power Unit Demonstrator (SPUD), Radiator Condenser for Space Environments, Design and Testing a Spray-Type Condenser for Zero-Gravity Operation, and Orbital Force Field Boiling and Condensing Experiments (OFFFACE)

- 2.310 CHEMISTRY AND CHEMICAL ENGINEERING DIVISION  
O. E. Dwyer and R. H. Wiswall (BNL-731 (p 18-46)), 1961

Heat transfer coefficients for Hg and NaK were verified by loops.

NSA 17:2461

- 2.310 NUCLEAR ENGINEERING DEPARTMENT PROGRESS REPORT, MAY 1, AUGUST 31, 1960  
(Brookhaven National Lab., Upton, N.Y.) 66 p.

Includes: liquid metal heat transfer, steel thermal convection loops containing Hg and Na, Mercury Test Loop, and NaK Heat Transfer Loop. (J.T.J.)

NSA 15:20477

- 2.310 NUCLEAR ENGINEERING DEPARTMENT PROGRESS REPORT, JANUARY 1 - APRIL 30, 1961.  
(BNL-671) August 1961, Contract AT(30-2)-Gen-16. 73 p.

Corrosion of materials by boiling Hg and Na is being studied. Corrosion and mass transfer in all liquid Hg loops are being compared with these phenomena in boiling loops. Developments are discussed for the NaK heat transfer loop and boiling potassium heat transfer loop.

NSA 15:31910

- 2.310 Reactor Development Program Progress Report for August, 1960  
Argonne National Lab.  
ANL-6215, 16 September 1960, 59 p.  
Contract W-31-109-eng-38

General research and development on water- and sodium-cooled reactors are reported along with specific development on EBWR-BORAX-V, EBR-I and EBR-II. Thermal and fast reactor safety studies are summarized in terms of fuel-coolant chemical reactions, kinetics of oxidation, ignition of reaction metals, and TREAT development. Developments in reactor fuels and materials, reactor components, separations, and advanced reactors are discussed in some detail.

NSA 15:2296

- 2.310 Dynamic Liquid-Metal Corrosion Studies (SRI)  
W. D. Weatherford, Jr., NASA TN-D-769, 1960

Hg gravity flow, two-phase test loop.

NSA 15:13285

- 2.310 See Also: 2.210, 4.100, 5.210, and 5.400.
- 2.310 MND-P-2128  
SNAP I DYNAMIC MERCURY LOOP TESTS OF SELECTED MATERIAL.  
 J. McGrew, The Martin Co., April 1960. Contract No. AT(30-3)-217.
- 2.310 MND-FILM-P-2042  
SNAP I CORROSION TEST LOOPS. The Martin Co., May 1959. Contract No. AT(30-3)-217
- 2.310 MND-P-2322  
SNAP III TOPICAL REPORT. R. Harvey, The Martin Co., February 1960. Contract No. AT(30-3)-217
- 2.310 ORNL-2431  
 Oak Ridge National Lab., Tenn.  
Molten-Salt Reactor Program Quarterly Progress Report for Period Ending October 31, 1957. 47 p. Contract W-7405-eng-26.

Nuclear Calculations. Additional calculations were made of the nuclear characteristics of two-region homogeneous molten-salt converter reactors. Critical inventory calculations revealed that for a 9-ft.-diameter core the minimum inventory would be about 100 kg of U<sup>235</sup>. Regeneration ratios were obtained as a function of inventory for a 600 Mw system, with Th concentration as a parameter. Gamma Heating of Core Vessel. It was estimated that for operation of the Reference Design Reactor at 600 Mw in a pure Ni core vessel 6 ft in diameter with 1 mole % ThF<sub>4</sub> in the fuel, core gamma rays will liberate 13.4 w/cm<sup>3</sup> in core vessel wall. Heating by gamma rays emitted in the blanket was found to be 0.97 w/cm<sup>3</sup>, and capture gamma rays originating in the wall were found to contribute 1.63 w/cm<sup>3</sup> to the heating. (Heat Transfer Systems. One system being studied transfers heat from the fuel salt to a coolant salt to Na to water, and the other system substitutes Hg for the Na. The electrical output for a 600 Mw (thermal) reactor would be 258.6 Mw with the Na system, and 295.8 Mw with the Hg system.) Metallurgy. Investigation of container materials for molten salts for reactor operation up to 1300° F reveals that Ni-base alloys are the most suitable. Since the corrosion resistance, and high temperature strength of Inconel are marginal, INOR-8 has been developed and its properties are being studied. Radiation Damage. An In-pile INOR-8 thermal convection loop for operation in the LITR with a BeF<sub>2</sub>-LiF-UF<sub>4</sub> fuel mixture is described. Chemistry. Phase diagrams are presented for the LiF-BeF<sub>2</sub>, NaF-BeF<sub>2</sub>, NaF-LiF-BeF<sub>2</sub>, LiF-BeF<sub>2</sub>-UF<sub>4</sub>, NaF-BeF<sub>2</sub>-UF<sub>4</sub>, LiF-ThF<sub>4</sub>, and NaF-ThF<sub>4</sub> systems. An analysis of the corrosion mechanism of fluoride fuels contained in Inconel or INOR-8 alloys indicates that Cr deposition will not result under anticipated conditions of the MSR.

NSA 12:5654

- 2.310 NDA-28  
 Nuclear Development Corp. of America, White Plains, N. Y.  
 Reactor Heat Transfer Progress (Issue No. 10. Unclassified Section 15J-14). Viscardi, John E., ed. July 10, 1956. Includes Translation: CHARACTERISTICS OF MERCURY BOILING IN THE TUBES OF A MERCURY VAPOR GENERATOR, by Loshkin, A. N. and P. I. Drol. Translated by John E. Viscardi from Zhur. Tekh. Fiz. 8, 1872-81 (1938). 26p. Contract AT(30-1)-862.

Some preliminary results of studies on heat transfer in polyphenyls are given. A transition state theory of the linear oxidation rates of metals is offered. A translation of an article on "Characteristics of Mercury Boiling in the Tubes of a Mercury-Vapor Generator" is included in part.

- 2.310 KAPL-M-EJP-2. Examination of the Forced Circulation Steam Generator from the Liquid Metal Heat Transfer Test Facility at Alplaus, N. Y. Report No. 2. Placzkowskii, E. J. April 11, 1954. Changed from Official Use Only Oct. 8, 1956. 19p. Sub-Project No. 70: Investigation of Alplaus Units. Contract W-31-109-Eng-52.

The metallurgical investigation of the forced circulation steam generator revealed the failure of two Type 347 stainless steel tubes (air outside, mercury inside). The two tubes were located at the top of the unit and the failures occurred at the tube sheet welds (both "hot" and "cold" ends). The cracking was attributed to thermal cycling involving temperatures and stresses above the design values.

NSA 11:3789



- 2.310 KAPL - M - LFE - 16  
Objective Study of Barrier Materials for Sodium-Water Systems  
Epstein, Leo F. (KAPL, Schenectady, N. Y. ) USAEC, 1955

By starting with 1st principles, various materials are eliminated for failure to meet the requirements for barrier materials for the Na-H<sub>2</sub>O reactor system. The term third fluid has been discarded because solids should also be considered. The only feasible materials are a solid barrier (with gas, e.g., He as the leak indicator), and metals which are liquid at room temperature, Cu and Ag are suggested as good possibilities. Among the liquid metals, only NaK (23:77, melting point 12°F) and Hg appear to be possibilities, with Hg in almost unequivocal favor except for its toxicity hazard, which it is believed can be controlled. Operating experience with Hg over a year has been satisfactory, while that with NaK suffered from difficulties with filling and cleaning, and accelerated corrosion. The expected high melting compound with Hg when Na leaks has failed to form.

CA 51:4158

## 2.320 POTASSIUM LOOPS

- 2.320 SPACE POWER PROGRAM SEMIANNUAL PROGRESS REPORT, JUNE 30, 1962  
ORNL-3337, pp 113-125.

- (a) Detailed results of second 316-K natural circulating loop, 3000 hours at 1600°F.
- (b) Description of Cb-12r loop test.
- (c) Results of first 316-K pumped loop test.
- (d) Descriptions of TZM, Haynes Alloy #25, and Cb-12r pumped loops.

- 2.320 SPACE POWER PROGRAM SEMIANNUAL PROGRESS REPORT, DECEMBER 31, 1961  
ORNL-3270, pp 91-104.

### Boiling K:

- (a) Good summary of all natural circulating loops.
- (b) Pressure-temperature profile on Inconel loop.
- (c) Metallographic, wt. change, and chemical results on Inconel and Haynes Alloy #25 loops.
- (d) Description of pumped loops.

- 2.320 NUCLEAR ENGINEERING DEPARTMENT PROGRESS REPORT, JANUARY 1 - APRIL 30, 1961  
(BNL-671) August 1961, Contract AT(30-2)-Gen16. 73 p.

Corrosion of materials by boiling Hg and Na is being studied. Corrosion and mass transfer in all liquid Hg loops are being compared with these phenomena in boiling loops. Developments are discussed for the NaK heat transfer loop and boiling potassium heat transfer loop.

NSA 15:31910

- 2.320 COMPATIBILITY OF MATERIALS WITH HIGH TEMPERATURE POTASSIUM, THIRD QUARTERLY PROGRESS REPORT, NOVEMBER 1, 1960 THROUGH JANUARY 31, 1961  
(NP-10147) (Rocketdyne Div., North American Aviation, Inc. Canoga Park, Calif.) March 3, 1961. Contract NAS 5-453. 62p. (R-2617-3)

Fabrication of loop equipment for studies of compatibility between Nb-1%Zr and liquid K is described. Results of a low temperature loop run are presented for Ta, Nb, Nb-1%Zr, and Mo, with Mo showing the least change. Results are also presented for bi-metal couples in K (Nb and Nb-1%Zr) and for alloy capsules (D.L.C.)

NSA 15:18505

2.320 ANP PROJECT SEMIANNUAL REPORT, OCTOBER 31, 1960  
ORNL-3029, p. 14.

- (a) 316-boiling K and Haynes Alloy #25 - boiling K capsule tests (with inserts) operated for 500 hours at 1500°F. Wt. losses in vapor (Haynes #25 4.6 mg/inch<sup>2</sup>; 316: 1.1 mg/in.<sup>2</sup>) Wt. gains in liquid: 2.4 mg/in.<sup>2</sup>  
(b) Inconel-boiling K. Capsule tests with inserts 1600°F, 1000 hours. Wt. loss in vapor: 10 mg/in.<sup>2</sup> Grain boundary attack: 10 mils.  
(c) 316-boiling K loop, 3000 hours, 1600°F, 50 ft/sec vapor flow, 180 gm/min mass flow.

2.320 COMPATIBILITY OF MATERIALS WITH HIGH TEMPERATURE POTASSIUM, FIRST QUARTERLY PROGRESS REPORT, MAY 1 THROUGH JULY 31, 1960  
(NP-10146) (Rocketdyne Div., North American Aviation, Inc., Canoga Park, Calif.) Aug. 31, 1960. Contract NAS 5-453. 35p (R-2617-1)

Several preliminary static capsule tests were made at 2000°F using Hastelloy-X as capsule material and He as internal atmosphere. The results for the Nb-Al<sub>2</sub>O<sub>3</sub> compatibility test run for 350 hr revealed a hardness increase and a small surface layer formed on the Nb tab. Results for the Nb-K compatibility test run for 25 hr indicated a slight weight loss in the wrought Nb tab - a mounting 59 0.83 and 1.43 mg/cm<sup>2</sup> day, and metallographic examination revealed no discernable attack on either Nb or Hastelloy-X by K. Dynamic capsule and loop equipment for future compatibility studies and mechanical property tests to be used are described. (D.L.C.)

NSA 15:18504

2.320 Liquid-Metals Research Program (NASA-Lewis), L. Rosenblum, NASA TN-D-769, 1960

Na and K capsule tests, Na and K loops, purification of alkali-metals, Na critical point experiment.

NSA 15:13280

2.320 Boiling Alkali Metal and Related Studies (ORNL)  
E. E. Hoffman, NASA TN D-769, 1960.

Na and K corrosion, K purification, K loop tests, and refluxing capsules.

NSA 15:13281

2.320 Liquid-Metal Boiling Systems (MSA), J. W. Mausteller, NASA TN-D-769, 1960.

K still shows thermal fatigue with massive nitriding in the vapor phase - vaporization of Na in a NaK loop - cover gas investigations - NaK loops to test among other things the inhibition of mass transport - purity of NaK and K - concept of operation with leaks.

NSA 15:13284

2.320 Liquid-Metal Investigation (GE-FPLD), J. W. Semmel, Jr., NASA TN-D-769, 1960

Na and K heat transfer loops, O<sub>2</sub> determination in K, new alloys of Cb showing a greater strength than Cb-1Zr have been developed, and capsule corrosion tests.

NSA 15:13275

2.320 Alkali Metal Corrosion Studies (Rocketdyne), R. J. Teitel, NASA TN-D-769, 1960.

Na and K loops, corrosion rates reported on various materials of containment. Bent reflux capsule tests were also completed.

NSA 15:13276

- 2.330 EFFECTS OF EXPOSURE OF AUSTENITIC AND FERRITIC STEELS IN SODIUM MASS TRANSFER TEST LOOPS\*, R. S. Young, T. Lauritzen, E. G. Brush, GE-APED, 12<sup>th</sup> Annual AEC Corrosion Symposium, May 20-22, 1963, Castlewood, Pleasanton, California

Continuation of a program at General Electric, APED, under AEC contract has provided the opportunity for extensive examinations of steel samples exposed to flowing sodium in six test loops. 316 stainless steel, 2½Cr-1Mo and 5Cr-½Mo-½Ti steel test samples were exposed at temperatures between 600°F and 1200°F, also low and high oxygen sodium at various velocities were used. Loops are constructed of the three test materials to provide a series of monometallic and bi-metallic systems in order to obtain information relative to the use of these materials in sodium-cooled reactor systems.

Carburization of 316 stainless steel, decarburization of 2½Cr-1Mo steel, preferential movement of chromium and nickel with respect to iron, and austenite-to-ferrite transformation were noted. In general, with the exception of observed carbon changes, the weight changes observed in 316 stainless steel hot-leg systems (316 SS, 2½Cr-1Mo, or 5Cr-½Mo, - ½Ti cold-legs) are reflected by the measured changes in surface concentrations of the major alloying constituents. Measurements of changes in surface composition and concentration gradients of these constituents in 316 stainless steel by x-ray fluorescence and electron microprobe techniques confirm and chart the growth of metallographically visible surface ferrite layers.

The mass transport of carbon in the bi-metallic systems containing 2½Cr-1Mo steel cold legs is dependent primarily upon the availability of a carbon sink such as provided by the 316 stainless steel.

\* This work was performed under Contract USAEC AT(04-3)-189, P.A.#15. This paper presents information in extension of that presented in May 1962 on the same subject, Metallurgical Changes in Mono- and Bi-Metallic Sodium Mass Transfer Test Loops at the 11th Annual AEC Corrosion Symposium.

- 2.330 Metallurgical Changes in Mono- and Bi-Metallic Sodium Mass Transfer Test Loops, F. J. Hetzler and R. S. Young, General Electric Co., Vallecitos Atomic Laboratory, Pleasanton, Calif. BNL 728(C-33) 1962.

Six sodium mass transfer loops were constructed of three alloys (316 stainless steel, Croloy 2½, and Croloy 5-Ti). Test specimens of the same respective materials were exposed at various sodium velocities and oxygen levels.

- 2.330 TID-7626 (Part 1)  
THE G.E. - APED SODIUM STUDY  
R. W. Lockhart and L. F. Epstein (NASA-AEC Liquid Metal Corrosion Meeting, Dec. 1961 at BNL).

Six loops operated up to 1300°F at  $\Delta$  t's as large as 500°F.  
Principal problem area was Mass Transport with subsequent plugging and loss of flow. (AGN Lib. 2-2786)

- 2.330 EXPERIENCE WITH EXPERIMENTAL SODIUM HEAT TRANSFER CYCLE  
Miroslav Pasck (Inst. of Nuc. Research Czech. Acad. of Sciences  
Jaderna energie 8:43-50(1962) (In Czech.)

.....The operation failures of the loop are analyzed and discussed.  
From the results it is possible to construct and operate a Na loop.

NSA 16:11834

- 2.330 MONTHLY TECHNICAL REPORT IN APADA ACTIVITIES, MAY 1962  
(Power Reactor Development Co., Detroit). Contract AT(11-1)-476.  
22 p. (PRDC-TR-59).

Research and development progress is reported on fuels and metallurgy, chemistry, materials, engineering analysis, graphite, physics, systems, mechanical design, electric systems and instrumentation, and test operations. (Includes Na).

NSA 17:7563

- 2.330 CNEN Program For a Mercury Binary Cycle Nuclear Power Plant.  
Aldo Forcella ( CNEN, Italy) Preprint Paper No. 14.  
NY Engineers Joint Council 1962 18p.

A program leading to construction of a prototype plant consisting of a Na-cooled fast reactor system in which the heat generated in the primary Na is used to raise the Hg vapor in a Na-Hg boiler is described. This vapor is then expanded in a turbo-generator set where part of reactor heat is converted to electricity. The exhaust Hg steam flows thru a condensor-H<sub>2</sub>O boiler where remaining heat energy is utilized to generate water steam which is then fed to another turbo generator thru a conventional steam cycle. Discussions of Hg plant equipment thermodynamics and economic considerations are included.  
NSA 16:31303

- 2.330 CA56-13735f  
"Experimental Heat Exchange Loop with Na Coolant," M. Pasek,  
Jaderna Energie 8:43-50(62). - A heat transfer loop containing 13 Kg of Na was built and used to obtain design and operational data ...The Na temperature was 150-170°. Circulation was by an e.m. pump. In the filtration bypass, the Na was filtered through SS filings while cooled to 150° with Tetralin. Some operational failures are analyzed; one was due to inter-crystalline corrosion of Cu by Na and Cu pipes were abandoned in favor of steel.

- 2.330 PRESENT STAGE OF DEVELOPMENT OF SODIUM-GRAPHITE REACTORS  
R. J. Beeley (Atomics International, Canoga Park, Calif.)  
Atom u. Strom, 7: No. 3, 17-22 (Mar. 1961). (In German).

The Sodium-Graphite Reactor has a series of characteristics which makes it very suitable for utilization as a heat source for stationary power plants. The present state of development of the SGR is explained on the basis of the construction materials, structural constituents, and the general technology. (tr-auth.)

NSA 15: 17848

- 2.330 PROGRESS IN THE DEVELOPMENT OF THE SODIUM GRAPHITE REACTOR  
R. W. Dickenson and H. Polak (Atomics International, Canoga Park, Calif.) Atomkernenergie 6: 9-15 (Jan. 1961) (In German).

Based on the results obtained from the Hallam Nuclear Power Facility, various design studies and economic calculations have been made for large sodium graphite reactor plants of present and of forecast 1962 technology.

NSA 15: 15219

- 2.330 EXPERIMENTAL EVALUATION OF A SODIUM-TO-SODIUM HELIFLOW HEAT EXCHANGER AT TEMPERATURES UP TO 1200° F  
J. S. McDonald (AI) Feb. 28, 1961. 41 p. Contract AT-11-1-GEN-8.  
(NAA-SR-5661)

A 100-Kw model heliflow-type intermediate heat exchanger was subjected to steady state and transient tests with Na at temperatures of 1200° F.

NSA 15: 14382

- 2.330 NUCLEAR REACTOR HEAT TRANSFER TECHNOLOGY  
M. E. Lapidès, General Electric Company, Pa.  
"Progress in Nuclear Energy," Ser. IV 4:29-50 (1961)

Contains analytical and experimental data on heat transfer for liquid metals. Effects considered include, among other things, surface roughness.

NSA 16:12831

- 2.330 TID-7626 (Part 1)  
LIQUID METAL INVESTIGATIONS  
J. W. Semmell, Jr. (GE-FPLD)  
(NASA-AEC Liquid-Metals Corrosion Meeting, Dec. 1961 at BNL)

Na and K in testing up to 1850°F for 1) heat transfer studies, 2) operation of a turbine with K vapor, 3) analysis of liquid metals, 4) development of materials for liquid metal containment, 5) the study of corrosion phenomena. Data included in report. (AGN Lib. 2-2786)

- 2.330 LAMS-2531, Quarterly Status Report on Lampre Program for Period Ending February 20, 1961.

The LAMPRE-I project is summarized in terms of capsule development and production, sodium system, cover gas system, capsule charge, shielding, and fuel storage facility. The loading of the LAMPRE-I core was begun on January 20, 1961 with the sodium temperature set at 160°C. The reactor was brought to criticality on February 17, 1961. Operation of Sodium Test Facility was continuous except for six maintenance and inspection shutdowns resulting in 680 idle hours. The intermediate sodium heat exchanger, steam generating unit, centrifugal sodium pumps, sodium flow control valves, and gas-fired sodium heaters are discussed. Heat transfer test results are given for the various components. Research and development activities for the LAMPRE program are reported in the topics fuel and alloy program, container alloy development, direct contact core studies, development of liquid fuels, container materials for reactor fuels, and fuel reprocessing.

- 2.330 NAA-SR5363 Corrosion and Radioactive Activity Transfer in the SRE Primary Sodium System, Oct. 30, 1961.

An evaluation extending over 2 years was made of primary system Na and of stainless steel, and Zr and Be specimens exposed in hot and cold legs of a bypass loop in primary system of Sodium Reactor Experiment (SRE). The metal specimens were checked for physical property changes and for radioactivity transfer of hot to cold leg surface. Stainless steel tabs underwent no significant micro-structural changes. However, the Zr specimen showed varying degrees of hydriding, generally characterized as moderate. Severe hydriding of one Zr tab resulted in serious embrittlement. Low O<sub>2</sub> pickup on Zr specimen verified hot-trap O<sub>2</sub> control of SRE primary system Na to less than 10 ppm, with a correspondingly low amount of oxidation of Zr moderator cans.

NSA 16:1191

- 2.330 TID-7626 (Part 1)  
CARBON TRANSFER IN LIQUID SODIUM SYSTEMS, W. J. Anderson, (AI)  
(NASA-AEC Liquid-Metals Corrosion Meeting, Dec. 1961 at NYC)  
Na and 304 stainless steel between 1000-1600°F  
Diffusion coefficients determined.  
(AGN Library 2-2786)

- 2.330 NAA-SR-4386,  
THE LARGE COMPONENT TEST LOOP  
H. Strahl,  
AT-11-1-GEN-8. OTS (AI) Mar. 1, 1960

2½ wt % chromium - 1 wt % molybdenum alloy steel pipe in nitrogen - blanketed Na at 1200 gal/min flow rates with temperatures up to 1000 F.

NSA 14:9737

- 2.330     NAA-SR-5282  
CARBURIZATION OF AUSTENITIC STAINLESS STEEL IN LIQUID SODIUM  
Anderson, W. J. and Sneesby, G. V.  
Atomics International, Div. of North American Aviation, Inc.,  
Canoga Park, Calif.  
1 September 1960 (Contract AT-11-1-Gen-8)

Results are presented of experimental research concerned with carbon transfer in liquid sodium - 304 stainless steel systems. The general nature of the reactions is discussed, and experimental techniques are described. The carburization rates for the steel were governed by diffusion rates. The content of 304 stainless steel in equilibrium with carbon-saturated sodium varies from 2.68% at 1000°F to 4.35% at 1600°F. Sodium containing 15 to 18 ppm carbon is in virtual equilibrium with uncarburized 304 stainless steel at 1200°F, when the oxygen concentration in sodium is less than 40 ppm. Diffusion coefficients for carbon in 304 stainless steel are presented in the temperature range of 1000°F to 1600°F. A method of using microhardness data from carburized stainless steel specimens for indirectly determining the carbon content of sodium is described.

NSA 14:24508

- 2.330     THE RHAPSODIE PROJECT  
John R. Ledue (France. Commissariat a l'Energie Atomique, Paris)  
(TID-7623 (p. 168-70))

The development program for the French Na-cooled plutonium-fueled fast breeder reactor, Rhapsodie, is discussed. The program calls for successive operation at 1 and 10 Mw and possibly at 20 Mw. (N.W.R.)

NSA 16: 28561

- 2.330     Sodium--Reactor Coolant  
Harbourne, B. L.  
United Kingdom Atomic Energy Authority, Risley, Lance, Eng.  
Chem & Proc. Eng. 40, 347-51 (1959) October

The advantages of using liquid sodium for a reactor coolant are discussed. The various practical considerations involved in designing sodium-cooled reactor systems such as sodium handling, materials selection for the circuit, and the destructive properties of sodium on the circuit are discussed.

NSA 14:3175

- 2.330     DEG-Memo-1166 Uncl.  
United Kingdom Atomic Energy Authority. Development and Engineering Group, Culcheth, Lancs, England.  
THE BEHAVIOUR OF A FAST REACTOR FUEL ELEMENT IN A DYNAMIC LIQUID SODIUM CIRCUIT.  
A. Thorley et al. August, 1960. 14p.  
...low corrosion rates for niobium and vanadium canning materials...

- 2.330     CORROSION PROBLEMS IN LIQUID METAL COOLED NUCLEAR REACTORS  
A. Draycott  
Chemical Processing, v. 13, Apr. 1960, p. 27-35.

Liquid metals are particularly suitable as coolants in fast reactors. Corrosion problems with Na are due mainly to the presence of oxygen in the metal. Stainless steel is suitable for use with liquid Na while Be and Cb require special precautionary measures.

(R6m; SS, Zr, Be, Cb, Bi, Na)

- 2.330     REACTOR DEVELOPMENT PROGRAM PROGRESS REPORT FOR SEPTEMBER 1960  
Oct. 14, 1960, 76 p.  
ANL-6234, Contract W-31-109-eng - 38. OTS.

NSA 15: 2297

- 2.330 Sodium Components Test Facility  
Atomic Power Development Associates, Inc., Detroit  
APDA-134, Nov. 1959, 208 p. Contract AT(11-1)-772

The design and construction of a test facility that will be capable of subjecting sodium components to both steady state and transient conditions expected in full size nuclear power electric generating stations are presented. This study encompasses design criteria, an estimate of time required to construct, and survey of existing facilities to be selected by mutual agreement of the commission and APDA which would be suitable to accommodate the desired tests.

NSA 14:10545

- 2.330 MSAR-59-99  
EFFECT OF 1200°F SODIUM ON AUSTENITIC AND FERRITIC STEELS  
J. W. Mausteller and R. C. Werner. Bi-monthly Progress Report No. 1 for July and August 1959 (on) THERMAL SHOCK, NITRIDING, STRESSED CORROSION, UNSTRESSED CORROSION. Sept. 16, 1959. 22 p. Contract AT(11-1)-765, MSA Research Corp. Callery, Penn.

Completion of preliminary designs for a thermal shock loop, a corrosion loop, and a nitriding loop is reported. Stressed and unstressed corrosion studies are scheduled to be carried out in the same system. A literature search was started, and various sites were contacted to avoid duplication of effort. It was found that some work has been done at 1200°F sodium temperature with various oxygen concentrations, however, part of the data is contradictory. Test plans include corrosion testing of Croloy and stainless steel samples as well as similar and dissimilar welds of these materials in 1200°F sodium. (J.R.D.)

NSA 14-3-2695

- 2.330 Liquid-Metal Boiling Systems (MSA), J. W. Mausteller, NASA TN-D-769, 1960

K still shows thermal fatigue with massive nitriding in the vapor phase - vaporization of Na in a NaK loop - cover gas investigations - NaK loops to test among other things the inhibition of mass transport - purity of NaK and K - concept of operation with leaks.

NSA 15:13284

- 2.330 Boiling Alkali Metal and Related Studies (ORNL)  
E. E. Hoffman, NASA TN-D-769, 1960.

Na and K corrosion, K purification, K loop tests, and refluxing capsules.

NSA 15:13281

- 2.330 Liquid-Metals Research Program (NASA-Lewis), L. Rosenblum, NASA TN-D-769, 1960

Na and K capsule tests, Na and K loops, purification of alkali-metals, Na critical point experiment.

NSA 15:13280

- 2.330 NASA TN-D-769, 1960  
ALKALI METAL CORROSION STUDIES  
R. J. Teitel, (Rocketdyne)

Na and K loops, corrosion rates reported on various materials of containment. Bent reflux capsule tests were also completed.

NSA 15:13276

- 2.330 TID 3544  
Mass Transfer in High-Temperature Sodium Loops. W. R. Holman.  
Nuclear Sci. and Engr. 2, No. 1, Suppl., 27-8(1959)June.

NSA 13:17336

Ames Lab., Ames, Iowa

- 2.330 Liquid-Metal Investigation (GE-FPLD), J. W. Semmel, Jr., NASA  
TN-D-769, 1960

Na and K heat transfer loops, O<sub>2</sub> determination in K, new alloys of Cb showing a greater strength than Cb-12r have been developed, and capsule corrosion tests.

NSA 15:13275

- 2.330 TID 12224, (TIM-490)  
TYPE 316 SS FORCED CONVECTION Na CORROSION LOOP TESTS SSSA-1A1,  
SSSA-2C2, SSSA-3C and SSA-SF1  
R. C. Shaw  
Pratt & Whitney Division of UAC, Conn., Aircraft Nuclear End.  
Lab., Middletown, Conn. July 2, 1958

General compatibility study of Na with 316 at temperatures from 1050 to 1600°F.

NSA 16:6692

- 2.330 A/CONF. 15/P/2291  
Smith, F. A.  
Argonne National Laboratory, Lemont, Illinois  
Sodium Technology for Nuclear Power Plants, 30p.

Prepared for the Second U. N. International Conference on the Peaceful Uses of Atomic Energy, 1958.

Sodium-cooled power reactors will require sodium flow rates through the reactor of 10,000 to 50,000 gpm at pressures up to 100 psi and temperatures up to 1,000 degrees F. The present sodium-cooled reactors are smaller than required for central power plants; however, a program including development of pumps and piping systems, sodium pre-heating methods, instrumentation, heat exchangers, mechanisms and seals, and sodium chemistry has been instituted. A large composite test facility duplicating the salient features of the EBR-II primary sodium reactor system and containing 5,000 gallons of sodium has been in operation since 1955. Further work has been done on sodium purification for higher temperature systems, permitting the use of oxygen sensitive materials. A broad program of investigation has been initiated in the field of heat exchanger design, and several large sodium cooled reactors are under construction which will contribute extensively to the technology of sodium.

NSA 12:15105

- 2.330 TID 3544  
Mass Transfer by High Temperature Liquid Sodium  
Interim Progress Report No. 2 Holman, W. R.  
American Standard, Atomic Energy Div. Mountain View, Calif.  
15 October 1958, 37p. Project D-14  
AECU-4072

Experiments were carried out in thermal convection loops in which sodium was induced by thermal convection to flow past a number of accurately weighed corrosion specimens located at close intervals throughout the entire temperature range existing within the loop. The specimens were accurately weighed prior to and following the test, and the weight changes were used as a measure of local mass transfer. Operating conditions, dimensions, materials, and temperature distributions are tabulated.

NSA 13:12647

- 2.330 COMPATIBILITY OF REACTOR MATERIALS IN FLOWING SODIUM.  
M. Davis and A. Draycott. Paper from "Peaceful Uses of Atomic Energy." v. 7. Reactor Technology. United Nations, Geneva, Switzerland, 1958, p. 94-110.

Measurement of the corrosion rate of Cb, C, 18-8 stainless steel, U, fission products and Zr in flowing Na as a function of flow velocity, temperature and use of deoxidants. 18 Ref.



- 2.330 ANL-6269  
REACTOR DEVELOPMENT PROGRAM PROGRESS REPORT  
Hilberry, N.  
(November 1960)

General research and development are reported on water-cooled and sodium-cooled reactors. Studies are also reported on reactor safety and nuclear technology (for preceding period, see Report ANL-6253).

- 2.330 SODIUM CORROSION AS A FUNCTION OF TIME  
McKee, John M.  
Nuclear Development Corp. of America, White Plains, N. Y.  
Preprint V-114, presented at NE&SC, April 6-9, 1959, Public Auditorium, Cleveland, Ohio  
New York, Engineers Joint Council, 1959, 20 p.

Periodic weight loss measurements were made on tabs suspended in duplicate stainless steel thermal convection loops circulating sodium between 1575 and 1100°F for 5000 hours. Considerable decay in corrosion rate was observed due to the formation of a protective ferritic layer of the tab surfaces.

NSA 13:20275

- 2.330 IGR-TN/C-857 Uncl.  
United Kingdom Atomic Energy Authority. Industrial Group.  
Culcheth Laboratories, Culcheth, Lancs, England.  
COMPATIBILITY OF REACTOR MATERIALS IN FLOWING SODIUM  
M. Davis and A. Draycott. 1958. 52 p. (ACR 15:202)
- 2.330 AERE-M/M-148  
Gt. Brit. Atomic Energy Research Establishment, Harwell, Berks, England.  
Metallurgical Investigations of Sodium Heat Transfer RIG. 18p. by  
Ward, A. G. and J. W. Taylor. Feb. 1957.

A study was made of the attack of stainless steel and Ni by Na, both oxygen free and contaminated, at temperatures in the range 300 to 600°C in static and dynamic tests. A number of miscellaneous metallurgical investigations on components taken from a stainless steel/Ni double annulus heat exchange rig are also reported. Under the conditions of test, stainless steel of the 18 wt. % Cr-8 Wt. % Ni type containing free carbide, undergoes considerable attack, both in static and dynamic tests in Na nominally free from and also heavily contaminated with O<sub>2</sub>. From the evidence available it is suggested that the mode of attack consists of a decarburizing action which proceeds intergranularly and modifies the spheroidal carbide in the affected region by diffusion of this phase into the matrix. Under similar test conditions Ni undergoes no detectable corrosion even at the highest temperature. It is recommended that prior inspection be carried out on stainless steel for use in systems containing Na at temperatures above 300°C, to ensure that the steel specification has been fulfilled and, that the material is devoid of free carbide.

NSA 11:9285

- 2.330 NRL-Memo-591, Naval Research Lab., Washington, D. C.  
The Transfer Rates of Radioactive Stainless Steel Components in Sodium Containing Barium. Final Report, Baus, R. A., A. D. Bogard, J. A. Grand and L. B. Lockhart and D. D. Williams. April 17, 1956.  
Project No. NS 200-021.

The effect of Ba on the transfer rates of Fe, Co, Ta, Mg and impurities in radioactive stainless steel at 425°C was measured with 0, 0.1, 1, and 10 wt. % Ba added to the Na. Type 347 stainless steel apparatus and radioactive sources were used. The presence of less than 1 wt.% Ba in Na containing 0.001 to 0.003 wt.% O<sub>2</sub> is effective in reducing the transfer rates of Fe<sup>59</sup>, Ta<sup>181</sup>, and Co<sup>60</sup>. The transfer rate of Mn<sup>54</sup> was not significantly reduced.

NSA 10:9284

- 2.330 100-MW NUCLEAR POWER PLANT UTILIZING A SODIUM COOLED, GRAPHITE MODERATED REACTOR  
(AI) NP-9236. Feb. 28, 1958. 103 p. (AI-2550) OTS.

NSA 14:26458

- 2.330 NAA-SR-4050. AI  
A. Siphon Break as a Blocking Valve  
J. McDonald and W. Marten

Runs were made with sodium at 500 and 940°F. The experiments were conducted to determine the feasibility of using the breaking of a syphon as a quick-acting means for stopping sodium flow following a loss of pump power.  
NSA 14:1106

- 2.330 TID 3544  
Mass Transfer by High Temperature Liquid Sodium. Interim Progress Report No. 1. W. R. Holman. Feb. 3, 1958. 22p.  
Project D-14. (AECU-4071) \$4.80(ph), \$2.70(mf) OTS.

NSA 13:12646

- 2.330 CORROSION AND CREEP BEHAVIOR OF TANTALUM IN FLOWING SODIUM.  
Gilbert E. Raines, C. Vernon Weaver, and John H. Stang (Battelle Mem. Inst., Columbus, O.). U.S. Atomic Energy Comm. BMI-1284, 29pp. (1958).

Ta tabs were suspended 8 to 50 days in the hot leg of Na pumped loops of type 316 stainless steel having max. temp. 1200°F. and min. 500 to 1000°F. In Na continuously gettered with Zr, wt. loss of Ta corresponded to 0.1 mil per year, and in Na continuously cold-trapped, 3 mils per year. Metallographic examn. indicated no localized attack except for severe intergranular attack of one group of arc-cast material exposed to Na high in O. During exposure O showed considerably stronger tendency to migrate from Ta to Na than predicted from available thermodynamic data. Creep tests at 1200° showed little if any difference whether conducted in He or in a pumped loop contg. Na continuously gettered with Zr.

NSA 12:16355  
CA53-3011e

- 2.330 ORNL 2 422 (Del)  
METALLURGY DIVISION ANNUAL PROGRESS REPORT FOR PERIOD ENDING Oct. 10, 1957. Dec. 13, 1957. Decl. with deletions Oct. 29, 1959. 147p. Contract W-7405-eng-26. OTS.

Na and NaK pumped Inconel loops. Studies include corrosion, mass transfer, H<sub>2</sub> embrittlement, and purification.

NSA 14:1763

- 2.330 A BRIEF REVIEW OF THERMAL GRADIENT MASS TRANSFER IN SODIUM AND NaK SYSTEMS J. H. DeVan and J. B. West. Feb. 11, 1957. 19p. Contract W-7405-eng-26 OTS  
Oak Ridge National Lab., Tenn. CF-57-2-146

The fact that material transport does occur under conditions of finite temperature difference in a flowing molten metal system was established. The rate mass transfer was thought to be either diffusion limited or solution rate limited. It is believed that the mass transfer of structural materials in Na or NaK systems is solution rate limited. The limiting process has not been qualitatively or quantitatively confirmed for the Inconel-Na or Inconel-NaK system. Increasing the maximum system wall temperature increases the amount of mass transfer, at least above 1300°F. The effect of the total temperature difference across the system on the amount of mass transfer was determined. (W.L.H.)

NSA 14:32691

- 2.330 LIQUID METAL FUEL REACTOR EXPERIMENT: REFERENCE DESIGN REPORT FOR AUGUST 1957  
274 p. (BAW-1019)

The design of the LMFRE is described and discussed.

- 2.330 THE CORROSION TESTING OF VARIOUS MATERIALS IN SODIUM. PART I.  
R. F. Dudek. PART II. K. Mildred Ferguson. Apr. 26, 1957. 39p.  
(BW-7020)

Tests were conducted to determine the corrosion resistance of various materials to liquid Na at a temperature of 1100°F. Four separate tests were conducted using a modified enclosed-rotor pump corrosion apparatus with Na at 1100°F and with the specimens at an absolute velocity of 55 ft/sec and static. The materials tested were a group of 300 and 400 series stainless alloys, low Croloys, carbon steel, Ni alloys, Zr, and Lukens clad stainless steels.

- 2.330 COMPONENTS - HIGH PURITY SODIUM SYSTEMS (LASL)  
J. E. Kemme, p. 229-33 of Proceedings of the 1957 Fast Reactor Information Meeting Held at Chicago, Ill., Nov. 1957.

A series of small, pumped, Na loops were run to ultimately discover a means of purifying Na.

NSA 13:16600

- 2.330 CF-572-146 (ORNL)  
A BRIEF REVIEW OF THERMAL GRADIENT MASS TRANSFER  
IN Na AND NaK SYSTEMS  
J. H. DeVan and J. B. West, February 11, 1957, 19 p.  
Contract W-7405-eng-26.

Mass transfer of structural materials in Na and NaK systems is solution rate limited. The limiting process has not been qualitatively or quantitatively confirmed for Inconel-Na or Inconel-NaK systems. Increasing the system wall temperature, above 1300°F, increases the amount of mass transfer. The effect of total  $\Delta T$  across the system on the amount of mass transfer was not determined.

CA 55:22945e

- 2.330 CF-57-7-115 (ORNL)  
Some Calculations of Diffusion Controlled Thermal Gradient Mass Transfer, J. J. Keyes, Jr. July 22, 1957. Decl. Oct. 9, 1959. 43p. Contract (W-8405-eng-26). OTS.

Calculations are presented of the amount of mass transfer to be expected in liquid alkali metal-Ni alloy systems for two assumed diffusion mechanisms. In one, the boundary layer is assumed saturated and the transfer rate is limited by the rate of diffusion of solute into the liquid. In the other, the mass transfer rate is assumed to be limited by the diffusion rate of a component of the solid alloy to the solid surface. It is concluded that a more general hypothesis is needed.

NSA 15: 5552

- 2.330 Material Transport in Sodium Systems  
Fred G. Haag (Gen. Elec. Co., Schenectady, N. Y.) Chem. Eng. Progr. Symposium Ser. 53, No. 20, 43-50(1957). (AGN Lib. C-1 3-689)

Data on the cause and magnitude of atom redistribution in flowing Na systems are summarized. System parameters are discussed, and O<sub>2</sub> concn. and temp. are shown to be the significant variables. The radioactivity from the growth of radioactive structural isotopes in typical Na-cooled reactor systems is small.

CA 51-16011d

- 2.330 NAA - SR - 1875  
SODIUM GRAPHITE REACTOR QUARTERLY PROGRESS REPORT [FOR] OCTOBER-DECEMBER 1956. R. L. Carter, ed. May 15, 1957. 56p

The circular moderator can core studies have been completed and core size recommendations are made. Some early results in the development of the edge loaded moderator can concept are given. Planned SRE low-flux experiments are listed in order. The problem of crystal growth on SRE hot cell windows is being studied. Work on metallurgy and modifications of fuel materials is summarized. The suggested maximum aging temperature (not accompanied by undesirable grain growth) for zirconium is 950°F. Tests on SRE cooling system components are summarized, with emphasis on the cold trap experiment. Control and safety rod tests are described.

- 2.330 THE USE OF SODIUM AND SODIUM-POTASSIUM ALLOY AS A HEAT-TRANSFER MEDIUM  
W. B. Hall and T. I. M. Crofts. Proc. Inst. Mech. Engrs. 170, 321-39  
(1956).

A No. of Na and Na-K circuits which have been built and operated over the past 3 years for heat-transfer experiments are described. The design and construction of liquid metal circuits and the components which are commonly used in them are discussed.

CA51-7065h

- 2.330 The Use of Sodium and Sodium-Potassium Alloy as a Heat Transfer Medium. Hall, W. B. and T. I. M. Crofts.  
Proc. Inst. Mech. Engrs. 170, 321-39 (1956)

A number of Na and NaK circuits which have been built and operated over the past 3 years for heat-transfer experiments are described. The design and construction of liquid metal circuits and the components which are commonly used in them are discussed.

CA 51:7065

- 2.330 PROGRESS REPORT NO. 29 FOR JUNE AND JULY 1955, J. W. Maustellier,  
ed. Aug. 19, 1955. 53 p. Contract NObs-65426. (NP-5739).

Tests at cyclic conditions were initiated on the Mark B 3000 Kw steam generator; the extent of NaK heat failures and water carry-over in the boiler was determined. Studies were continued on the natural circulation of liquid metal system components around heated vertical cylinders and about the heat transfer characteristics of liquid metals in cross flow. Modifications and improvements were made on the electromagnetic pumps, liquid level gages, and pressure gages. The effect of pretreatment of the surfaces on the wetting of surfaces with liquid Na was investigated. Testing continued on the valve welds and the Mark A bellows. The studies of irradiation hazards arising from reactor cooling system leaks and from chemical reactions between steam and reactor molten metals were continued. The removal of residual radioactive Na using sodium flushes was shown to be dependent upon the degree of mixing of the flush and residual sodium. (For preceding period see NP-5690)

- 2.330 NP-5690  
Progress Report No. 28 for April and May 1955, J. W. Mausteller, ed.  
June 21, 1955. 70p. Contract NObs-65426.

Tests on the Mark B 3000-Kw steam generator were continued. Engineering studies are summarized on vent and line closures, cross flow exchanger, electromagnetic pumps, pressure gages, liquid metal leakage, alkali liquid metal surface wetting, corrosive effects and waste disposal of Na, and testing of Mark A and B bellows, valves, and apparatus for thermal shock measurements. The changes in the solubility of Na<sub>2</sub>O in liquid Na due to the addition of Na or K were investigated. Mass transfer inhibition was examined. The removal of radioactive Na by flushing was investigated. Loop tests and pipe-flushing tests were continued. The radiation hazards arising from leaks in the water cooling system of a reactor and the possible chemical reactions between water and molten metals were studied. (For preceding period see NP-5601.)

- 2.330 CF-55-6-24, Oak Ridge National Lab., Y-12 Area, Tenn.  
Examination of Inconel-316 Stainless Steel-Sodium Pump Loops 4689-5 and 4689-6, Adamson, G. M. and R. S. Crouse. June 2, 1955.  
Decl. April 4, 1956. 12 p. Contract W-7405-eng-26.

The findings of a metallographic examination of the loops confirm the fact that excessive mass transfer occurs in Inconel pump loops in which Na is circulated at 1500°F. The use of 316 stainless steel in the cold leg of the loops does not appear to increase mass transfer.

NSA 10:10832

- 2.330 EW-3794  
Markert, W., Jr.  
Babcock and Wilcox Co. Research Center, Alliance, Ohio  
The Investigation of Corrosion and Mass Transport with Sodium  
in a Figure-Of-Eight Circuit. August 9, 1954. 20p.

An apparatus for studying corrosion and mass transport under simulated sodium-cooled reactor conditions is described. The operation of the figure-eight loop with sodium on Globeiron specimens is reported. The Globeiron showed a very slight weight loss, probably from decarburization, and there was no evidence of mass transfer. NSA 12:13112

- 2.330 CF-54-8-225  
Oak Ridge National Lab., Tenn.  
Some Observations Made on Cavitating Sodium Flow in a Venturi  
J. M. Trummel. Aug. 31, 1954. 10p Contract W-7405-eng-26.

Cavitating sodium flow was obtained in the venturi of an isothermal loop at temperatures from 1215 to 1475 °F. Cavitation was detected in three ways: by observing the minimum venturi throat pressure, by observing the loop pressure drop, and by listening to the flow noise. Cavitation occurred promptly when venturi throat pressure was reduced to within about 1.5 psia of vapor pressure. Venturi wall damage due to cavitation has not been determined. NSA 11:13710

- 2.330 PRELIMINARY DESIGN OF A ZIRCONIUM CANNED GRAPHITE TANK-TYPE  
POWER REACTOR  
J. Henrie (North American Aviation, Inc., Downey, Calif.)  
April 30, 1953. Decl. Nov. 6, 1958. 7 p. (NAA-SR-Memo-681)

Design details of a Na-cooled graphite-moderated power reactor of the tank-type is given.

NSA 15: 14029

- 2.330 RDW(W)-8054  
Heat Transfer Experiments with Sodium  
Hall, W. B. and Jenkins, A. E.  
Windscale Works, Sellafield, Cumb., England  
June 1953, 19p.

The theoretical approach to the problem of heat transfer in liquid metals is briefly reviewed. The difference between this approach and that used in the case of fluids with a high Prandtl number is due to the fact that the thermal conductivity of a liquid metal may be so high as to swamp the "eddy conductivity" in a turbulent stream. A description is given of experiments in which the heat transfer coefficients between two annuli each carrying a flow of sodium were measured. Since a direct comparison with results obtained with a circular tube is not possible, the results are in quite good agreement with the theoretical values given. In the course of the work it was found that there were significant variations in temperature around the annuli carrying the liquid metal in the heat exchanger. It is thought that these variations were due to a slight eccentricity of the exchanger tubes. An approximate theoretical treatment indicates that such variations are likely to be greater (when expressed as a fraction of the overall temperature difference) in the case of liquid metals than in the case of fluids with a high Prandtl number. In these experiments, where the heat flux was about 50 watts per cm<sup>2</sup>, the temperature variations were quite small, but if full advantage is taken of the liquid metal to obtain high heat fluxes, they might be so large as to produce serious thermal stresses and distortion of the heat exchanger.

NSA 13:12925

- 2.330 TID 3305-930  
CORROSION AND OTHER FACTORS IN THE APPLICATION OF SODIUM TO THE KAPL  
REACTOR. L. F. Epstein and C. E. Weber. Dec. 15, 1948. Decl.  
Mar. 25, 1957. 38p. KAPL-M-LFE-r

Data accumulated on the nature of the engineering and technological problems involved in the use of liquid Na as a heat transfer medium in a nuclear reactor are presented. Some possible solutions are included.

- 2.330 ANL - 4417  
Resistance of Materials to Attack by Liquid Metals  
L. R. Kelman, W. D. Wilinon, F. L. Yaggee.

Na and NaK corrosion results are included. Mass transfer problems leading to plugging of loops were observed at high temperatures and when oxygen content was high in Na or NaK.

---

2.340 NaK LOOPS

- 2.340 "Corrosion of Stainless Steel Tube by Liquid Na Systems: II - Results and Discussions for Thermal Convect. Corrosion Test,"  
by H. Atsumo, Nippon Genshiryoku Gakkuski 4:281-7, May 1962  
(In Japanese).

A newly formed thermal convection testing apparatus in high temperature NaK was used. NaK was circulated at a comparatively slow rate in the time range 500-1500 hours at 600°C. The inner wall of the specimen tubes were examined by microscopic examination. The results are as follows: (1) The shapes of inward deposited metals in tubes are the most important fact in this case; (2) At a low flow rate there was no change for steel composition or welding method after long exposure time; (3) With lapse of exposure time, microstructure of the specimens differed slightly from original state (especially, deposited metal parts).

NSA 16:27594

- 2.340 AD 277379, Research on Liquid Metals as Power Transmission Fluids  
G. E. Co., Schenectady, N. Y. May 1958 - March 1962.  
(WADD 57-294 Part 3) Unclassified.

A liquid metal test loop consisting of a low press. flow control and monitoring loop and a high-pressure loop was debugged and tested at temperatures to 550°F. A total operating time of 103 hrs was accrued. Techniques for loop repair and maintenance were developed. A two-staged gear driven pump rated at 3000 psi, 1000°F and 1 gal/min was designed, built, and tested; the pump was first operated with petroleum ether (Stoddard Solvent) to determine its capability. A total of 10 hrs running was accumulated during which time the pump generated 3000 psi and flows exceeding 2 gal/min at approximately 1/2 rated speed. The pump was run for 3½ hrs on NaK-77 at pressures up to 640 psi and temperatures to 780°F. Rated flow was developed at half rated speed. Tests were terminated by failure of an outlet flange stud and incipient bearing failure. Limited data was obtained and over-all efficiency was calculated. Material testing NaK-77 to determine compatibility, function, and wear rates and a literature survey were also conducted.

- 2.340 CHEMISTRY AND CHEMICAL ENGINEERING DIVISION  
O. E. Dwyer and R. H. Wiswall (BNL-731 (p 18-46))

Heat transfer coefficients for Hg and NaK were verified by loops.

NSA 17:2461

- 2.340 The Embrittlement of Nb in H<sub>2</sub> Contaminated NaK,  
A. Thorley, E. C. Tyzack (Reactor Materials Lab, Culcheth, Eng.)  
Preprint SM 26/49, 34 p. (To be printed in the Proceedings of  
IAEA Symposium on Thermodynamics of Nuclear Materials, held in  
Vienna, 21-25 March 62).

A study was made of uptake and equilibrium levels of H<sub>2</sub> attained by Nb specimens exposed to dynamic NaK (70% K) alloy circulated in an electro-magnetic pumped circuit at 350°C.... The extent of embrittlement of Nb at various H<sub>2</sub> levels was also evaluated by mechanical tests.

NSA 16:25402

2.340

NUCLEAR ENGINEERING DEPARTMENT PROGRESS REPORT, JANUARY 1 - APRIL 30, 1961  
(BNL-671) August 1961, Contract AT(30-2)-Gen-16. 73 p.

Corrosion of materials by boiling Hg and Na is being studied. Corrosion and mass transfer in all liquid Hg loops are being compared with these phenomena in boiling loops. Developments are discussed for the NaK heat transfer loop and boiling potassium heat transfer loop.

NSA 15:31910

2.340

NUCLEAR ENGINEERING DEPARTMENT PROGRESS REPORT, MAY 1, AUGUST 31, 1960  
(Brookhaven National Lab., Upton, N. Y.) 66 p.

Includes: liquid metal heat transfer, steel thermal convection loops containing Hg and Na, Mercury Test Loop, and NaK Heat Transfer Loop. (J.T.J.)

NSA 15:20477

2.340

Liquid Metal Heat Exchangers. K. B. Schumacher.  
American Society of Naval Engineers, Inc., Journal, v. 72, Nov. 1960, p. 779-782.

Design and operation of a liquid metal heat exchanger. Corrosion of components by the NaK system. Prevention of tube leakage and failure by proper design and a manual relief valve system. 7 ref.

2.340

Liquid Metal Boiling Systems (MSA), J. W. Mausteller, NASA TN-D-769, 1960

K still shows thermal fatigue with massive nitriding in the vapor phase - vaporization of Na in a NaK loop - cover gas investigations - NaK loops to test among other things the inhibition of mass transport - purity of NaK and K - concept of operation with leaks.

NSA 15:13284

2.340

Development Testing of Liquid Metal and Molten Salt Heat Exchangers  
McPherson, R. E., Amos, J. C., and Savage, H. W.  
Oak Ridge National Laboratory, Tennessee  
Nuclear Science and Engineering, 8, 14-20 (July 1960)

In order to investigate the design and fabrication problems inherent in compact, high-performance heat exchangers for aircraft nuclear propulsion applications, extensive development testing was done on bifluid (molten salt-NaK) heat exchangers and on liquid metal (NaK-air) radiators. These test units were prototypes of the heat transfer equipment which was to be used in the Aircraft Reactor Test (ART) at ORNL. Five bifluid test loops and one liquid metal test loop were used for performance and endurance testing of these components at simulated reactor operating conditions. The molten salt used was a ternary mixture of composition NaF 50 mole %, ZrF<sub>4</sub> 46 mole %, UF<sub>4</sub> 4 mole %. The NaK used was 56 wt % Na and 44 wt % K. A total of 47,000 hr of operation at 1200 to 1700 F was accumulated on 18 heat exchangers and 20 radiators. The program demonstrated that the compact heat exchanger geometries tested possessed the performance capabilities and mechanical integrity to meet ART design requirements.

NSA 14:19109

2.340

PWAC-593, (Secret). Pratt and Whitney Aircraft Division, United Aircraft Corporation, Middletown, Connecticut., Nuclear Propulsion Program Engineering Progress Report for July 1, 1959 - September 30, 1959. October, 1959. 127 p.

... NaK corrosion loops examined... ACR 16:215

- 2.340     Development Testing and Performance Evaluation of Liquid Metal and Molten Salt Heat Exchangers  
MacPherson, R. E. and Yarosh, M. M.  
Oak Ridge National Lab., Tennessee  
CF-60-3-164 March 17, 1960

Development testing was done on prototype, bifluid (molten salt-NaK) salt exchangers and on liquid metal (NaK-air) radiators in support of the ANP program. The molten salt was a Na-Zr-UF<sub>4</sub> mixture, and the NaK was 56 wt % Na and 44 wt % K. Performance tests were conducted in prototypes of the main heat exchangers for the Aircraft Reactor Test. The flow range on the molten-salt side of the exchanger varied from Reynolds numbers of 1000 to 6000, and the NaK-flow operating range varied from Reynolds numbers of 15,000 to 200,000. Data were taken on 20-, 25-, and 100-tube bundles at start-up and after 500 and 1000 hr of operation. No deterioration of the salt coefficient occurred with time of operation. In general, the data were found to lie approximately 40% below the Dittus-Boelter line in the Reynolds range of interest. The effects of tube spacer arrangements on the unit performance were investigated. Pressure-drop data are presented for 1.75- and 0.5 MW Aircraft Reactor Test prototype radiator units.

NSA 14:24216

- 2.340     ORNL 2 422 (Del)  
METALLURGY DIVISION ANNUAL PROGRESS REPORT FOR PERIOD ENDING OCT. 10, 1957. Dec. 13, 1957. Decl. with deletions Oct. 29, 1959. 147p. Contract W-7405-eng-26. OTS.

Na and NaK pumped Inconel loops. Studies include corrosion, mass transfer, H<sub>2</sub> embrittlement, and purification.

NSA 14:1763

- 2.340     CF-572-146 (ORNL)  
A BRIEF REVIEW OF THERMAL GRADIENT MASS TRANSFER IN Na AND NaK SYSTEMS  
J. H. DeVan and J. B. West, February 11, 1957, 19 p.  
Contract W-7405-eng-26.

Mass transfer of structural materials in Na and NaK systems is solution rate limited. The limiting process has not been qualitatively or quantitatively confirmed for Inconel-Na or Inconel-NaK systems. Increasing the system wall temperature, above 1300°F, increases the amount of mass transfer. The effect of total  $\Delta T$  across the system on the amount of mass transfer was not determined.

CA 55:22945e

- 2.340     PWAC-203 MSA-Callery Chem Co. Mass Transfer Program Summary  
F. Paradise and G. Austin, PW Aircraft Oct 28, 1957  
Cont AT(11-1)-229

Mass transfer tests in forced circulation, poly metallic loops were conducted at operating temps of 1200°F and 1450°F in an effort to evaluate various system materials and high temp liq metal environment. NaK (56% Na) was used. Inconel & Hastelloy-X were 2 of mat'ls evaluated. Most of the attack of hot legs appeared to be selective; occurring at either a leached zone or grain-boundary corr. (also decarburization).

NSA 16:15146

- 2.340     BW-3988  
Babcock and Wilcox Co. Research Center, Alliance, Ohio.  
Investigation of the Corrosion and Mass Transport Resistance of Structural Materials to Liquid Sodium. Part I. Dudek, R. F.  
Part II. Ferguson, K. Mildred. April 23, 1957. 41 pages.

These tests were conducted to determine the corrosion and mass transport resistance of various structural materials to liquid sodium in a dynamic test loop operating at a temperature differential.

NSA 12:7807



- 2.340 Compatibility of Inconel with Boiling Alkali Metals: D. H. Jansen and E. E. Hoffman, Oak Ridge National Laboratory. (1960)

Nickel-base alloys have numerous physical and mechanical properties which make them potentially useful for containing alkali metals at elevated temperatures. Alkali metals are currently being considered as working fluids for Rankine-cycle turbo-generator systems for space power applications. The results of studies to determine the compatibility of Inconel with boiling rubidium, sodium, and potassium at temperatures up to 1600°F for several thousand hours are presented.

- 2.340 IGR-TN/W-454  
Gt. Brit. Windscale Works, Sellafield, Cumb., England  
Mass Transfer in Liquid Metal Circuits. A Review of Progress in Initial Studies by Draycott, A. and P. D. Rich. Jan. 1957. 12p. (IGC-FRDC/P-217; IGC-SGDC/P-8)

Significant mass transfer of stainless steel constituents, and to a lesser extent of Zr has been measured in NaK circuits. In the first instance, at least, the oxide content of the liquid metal was a contributory influence. Solubility-temperature.....

- 2.340 NP-6051, Mine Safety Appliances Co., Callery, Penna.  
Corrosion of Low Alloy Steel in Hot NaK  
Memo Report 109. W. Milich and E. C. King, Mar. 30, 1956. 6 p.  
Contract NObs-65426.

Consideration is being given to the use of low alloy steels due to the difficulties encountered in the use of type 347 stainless steel for steam generating equipment. As a preliminary experiment, to check the corrosion of such steels by liquid metals, a type 304 stainless steel loop was revised to accommodate a section of 1 in. OD tubing composed of 2½% Cr-1% Mo steel. NaK (56 wt. % K) at 850°F was circulated at approximately 8 ft/sec. through this tubing for four months. Four small samples (¼ in. weighed sections of the tubing) placed in an in-stream expansion tank were removed after 1, 2, 3, and 4 months immersion time and showed penetration of 0.19, 0.09, 0.07, and 0.06 mills/yr respectively. The section of test tubing showed no detectable weight loss after the 4 month period. With the temperature of the NaK at 850°F the oxygen content was found to be 0.032 wt. % O<sub>2</sub>. All results of the test run isothermally at 850°F indicated a rate of attack less than one mil per year. (auth) NSA 10-8373

- 2.340 The Use of Sodium and Sodium-Potassium Alloy as a Heat Transfer Medium. Hall, W. B. and T. I. M. Crofts. Proc. Inst. Mech. Engrs. 170, 321-39 (1956)

A number of Na and NaK circuits which have been built and operated over the past 3 years for heat-transfer experiments are described. The design and construction of liquid metal circuits and the components which are commonly used in them are discussed.

CA 51:7065

- 2.340 THE USE OF SODIUM AND SODIUM-POTASSIUM ALLOY AS A HEAT-TRANSFER MEDIUM. W. B. Hall and T. I. M. Crofts. Proc. Inst. Mech. Engrs. 170, 321-39 (1956).

A no. of Na and Na-K circuits which have been built and operated over the past 3 years for heat-transfer expts. are described. The design and construction of liquid metal circuits and the components which are commonly used in them are discussed.

CA51-7065h

- 2.340 CF-55-11-102  
CHEMICAL EXAMINATION OF COLD TRAP FROM INTERMEDIATE HEAT EXCHANGER TEST STAND NO. 1, J. C. White, Nov. 17, 1955. 4p.

The oxide remaining in the cold trap of the NaK system was analyzed and the results are given and discussed.

2.340

KAPL - M - LFE - 16  
Objective Study of Barrier Materials for Sodium-Water Systems  
 Epstein, Leo F. (KAPL, Schenectady, N. Y. ) USAEC, 1955

By starting with 1st principles, various materials are eliminated for failure to meet the requirements for barrier materials for the Na-H<sub>2</sub>O reactor system. The term third fluid has been discarded because solids should also be considered. The only feasible materials are a solid barrier (with gas, e.g., He as the leak indicator), and metals which are liquid at room temperature, Cu and Ag are suggested as good possibilities. Among the liquid metals, only NaK (23:77, melting point 12°F) and Hg appear to be possibilities, with Hg in almost unequivocal favor except for its toxicity hazard, which it is believed can be controlled. Operating experience with Hg over a year has been satisfactory, while that with NaK suffered from difficulties with filling and cleaning, and accelerated corrosion. The expected high melting compound with Hg when Na leaks has failed to form.

CA 51:4158

2.340

KAPL-M-EGB-19  
 Knolls Atomic Power Lab., Schenectady, N. Y.  
Carburization of Stainless Steel in Sodium, Report No. I.  
 Preliminary Analysis by Brush, E. G. July 14, 1955, 41 p.  
 Contract W-31-109-Eng-52.

It is concluded that Type 347 stainless steel is subject to grain boundary carburization in Na contaminated with carbon. Equations for calculating the carburization depth are given.

NSA 11:12467

2.340

KAPL-M-WLF-5  
 Knolls Atomic Power Laboratory, Schenectady, N. Y.  
Examination of the Natural Circulation Steam Generator From the Liquid Metal Heat Transfer Test Facility at Alplaus, New York.  
 Report No. 2  
 Callahan, E. J. and W. L. Fleischmann  
 September 12, 1953. Changed from Official Use Only Oct. 8, 1956. 35p.  
 Problem No. 70: Investigation of the Causes of Cracking in the Natural Circulation. Contract W-31-109-Eng-52

The first structural failure of a heat exchanger used in the Alplaus liquid metal system is discussed. The metallurgical examination revealed failure of two Type 347 stainless steel tubes (NaK outside, mercury inside) and two tube sheets. The location of the failure was confined to the hot end and the area around these two hottest tubes. Judging by the fracture appearance, the majority of the cracks were caused by thermal cycling. Further studies are under way to establish more definitely the cause of the failure.

NSA 11:3791

2.340

ANL-4417  
Resistance of Materials to Attack by Liquid Metals  
 L. R. Kelman, W. D. Wilinon, F. L. Yaggee.

Na and NaK corrosion results are included. Mass transfer problem leading to plugging of loops were observed at high temperatures and when oxygen content was high in Na or NaK.

- 2.350 EFFECTS OF EXPOSURE OF AUSTENITIC AND FERRITIC STEELS IN SODIUM MASS TRANSFER TEST LOOPS\*, R. S. Young, T. Lauritzen, E. G. Brush, GE-APED, 12<sup>th</sup> Annual AEC Corrosion Symposium, May 20-22, 1963, Castlewood, Pleasanton, California

Continuation of a program at General Electric, APED, under AEC contract has provided the opportunity for extensive examinations of steel samples exposed to flowing sodium in six test loops. 316 stainless steel, 2½Cr-1Mo and 5Cr-½Mo-½Ti steel test samples were exposed at temperatures between 600°F and 1200°F, also low and high oxygen sodium at various velocities were used. Loops are constructed of the three test materials to provide a series of mono-metallic and bi-metallic systems in order to obtain information relative to the use of these materials in sodium-cooled reactor systems.

Carburization of 316 stainless steel, decarburization of 2½Cr-1Mo steel, preferential movement of chromium and nickel with respect to iron, and austenite-to-ferrite transformation were noted. In general, with the exception of observed carbon changes, the weight changes observed in 316 stainless steel hot-leg systems (316 SS, 2½Cr-1Mo, or 5Cr-½Mo, - ½Ti cold-legs) are reflected by the measured changes in surface concentrations of the major alloying constituents. Measurements of changes in surface composition and concentration gradients of these constituents in 316 stainless steel by x-ray fluorescence and electron microprobe techniques confirm and chart the growth of metallographically visible surface ferrite layers.

The mass transport of carbon in the bi-metallic systems containing 2½Cr-1Mo steel cold legs is dependent primarily upon the availability of a carbon sink such as provided by the 316 stainless steel.

\* This work was performed under Contract USAEC AT(04-3)-189, P.A.#15. This paper presents information in extension of that presented in May 1962 on the same subject, Metallurgical Changes in Mono- and Bi-Metallic Sodium Mass Transfer Test Loops at the 11th Annual AEC Corrosion Symposium.

- 2.350 SNAP-8 MATERIALS TASK GROUP REPORT, AD-HOC COMMITTEE REPORT  
L. Rosenblum, NASA (Chairman)  
Pub. by Aerojet General Corporation, Azusa  
August 20, 1962

Review of critical problem areas relative to long life mercury and NaK systems. The neglected development of the NaK system and the poor corrosion resistance of the Haynes 25 alloy in mercury were discussed.

- 2.350 LAMS - 2531  
QUARTERLY STATUS REPORT ON LAMPRE PROGRAM FOR PERIOD ENDING  
FEBRUARY 20, 1961. Anon Contract W-7405-eng-36. 26 p.

The LAMPRE-I project is summarized in terms of capsule development and production, sodium system, cover gas system, capsule charge, shielding, and fuel storage facility. The loading of the LAMPRE-I core was begun on January 20, 1961 with the sodium temperature set at 160°C. The reactor was brought to criticality on February 17, 1961. Operation of the Sodium Test Facility was continuous except for 6 maintenance and inspection shutdowns resulting in 680 idle hours. The intermediate sodium heat exchanger, steam generating unit, centrifugal sodium pumps, sodium flow control valves, and gas-fired sodium heater are discussed. Heat transfer test results are given for the various components. Research and development activities for the LAMPRE program are reported in the topics fuel and alloy program, container alloy development, direct contact core studies, development of liquid fuels, container materials for reactor fuels, and fuel reprocessing.

- 2.350 AD-282370  
INVESTIGATION OF LIQUID METAL BOILING HEAT TRANSFER. QUARTERLY  
PROGRESS REPORT NO. 3 ON PHASE 2A  
Balzhiser, Richard E., Colver, C. Philip, and others.  
July 1962. Michigan U. Coll. of Engineering, Ann Arbor

Potassium will be boiled from the outside of a 3/8 in. OD Haynes-25 tube at temperatures up to 2000°F and heat fluxes of 10 to the 6th power Btu/hr sq ft. This study is intended to obtain experimental data for the nucleate boiling of potassium at fluxes near the critical. The effect of pressure on the critical flux will be investigated. Film boiling studies employing potassium as the test fluid and sodium as the heating fluid will be conducted. Boiling will occur from a 0.200 in. Nb-1% Zr disk in a 1 in. Nb-1% Zr tube. A forced circulation liquid metal loop will circulate potassium at liquid flow rates up to 2 gpm. The maximum fluid temperature in the loop will be 1800°F. Potassium will be preheated to various qualities using clamshell heaters. Condensing sodium is used to boil the potassium in the test section. Fluxes of up to 10 to the 6th power Btu/hr sq ft are anticipated. Two phase flow studies will be conducted as a part of the forced circulation investigation. Pressure drop and void fraction measurements will be made for different qualities and flow rates. Loop instrumentation will be used in conjunction with the pool boiling studies. Agravic studies with mercury are scheduled. Studies will be from 1 - 20 g's with the liquid level varied to insure uniform pressures at liquid-vapor and liquid-solid interfaces. (Author)

- 2.350 MARTIN - ANPP CORROSION TESTING PROGRAM METHODS AND PROCEDURES  
(Martin Co. Nuclear Div., Baltimore) Feb. 1961. Contract DA-44-009-ENG-3581). 89 p.

Methods and procedures utilized in the ANPP Corrosion Test Program are outlined. Included is a description of the primary and secondary loop systems, miniature heat exchangers, sampling procedures, and chemical analysis techniques.

NSA 15:14658

- 2.350 CARBURIZATION OF AUSTENITIC STAINLESS STEEL IN LIQUID SODIUM  
Anderson, W. J. and Sneesby, G. V.  
Atomics International, Div. of North American  
Aviation, Inc., Conago Park, Calif.  
NAA-SR-5282, 1 September 1960 (Contract AT-11-1-Gen-8)

Results are presented of experimental research concerned with carbon transfer in liquid sodium - 304 stainless steel systems. The general nature of the reactions is discussed, and experimental techniques are described. The reaction rates in the liquid sodium system were found to be rapid, and carburization rates for the steel were governed by diffusion rates. The carbon content of 304 stainless steel in equilibrium with carbon-saturated sodium varies from 2.68% at 1000°F to 4.35% at 1600°F. Sodium containing 15 to 18 ppm carbon is in virtual equilibrium with uncarburized 304 stainless steel at 1200°F, when the oxygen concentration in sodium is less than 40 ppm. Diffusion coefficients for carbon in 304 stainless steel are presented in the temperature range of 1000°F to 1600°F. A method of using micro-hardness data from carburized stainless steel specimens for indirectly determining the carbon content of sodium is described.

NSA 14:24508

- 2.350 TID 12232, TID 12245 (TIM-573) also TIM-435 dated  
September 19, 1958, Hastelloy-X Type 316 SS Forced Convection  
Na Corrosion Loop Test, HXLM-3, R. C. Shaw, P&W AC Div, UAC,  
Conn. Aircraft Nuclear Engine Lab, Middletown, Conn.) Sept. 23,  
1958, Contract AT(11-1)-229

Na was pumped through a loop constructed of Type 316 SS with a Hastelloy-X heater leg and an Inconel pump cell to determine ability of an essentially bimetallic system to resist corrosion and mass transfer. Temperature 1700°F to 1050°F. Corrosion Rate: 3.5 mils but deposits of 32 mils (primarily of Cr and Ni.)

NSA 16:15147

- 2.350 ORNL-2340 (Pts 1-5) Aircraft Nuclear Propulsion  
Proj. Report (to June 30, 1957) - Includes information on fabri-  
cation of Na to NaK, NaK to air and fuel to NaK.  
NSA 16:28647

- 2.350 AD 256511  
PROGRESS REPORT NO. 36 FOR AUGUST AND SEPTEMBER, 1956  
Posey, W. J. (Ed.)  
Mine Safety App. Co., Callery, Penn. NP-6132, 70 p. (Oct. 10,  
1956)

Tests are continuing on the 3000 KW steam generator. The unit has been subjected to a life test at cyclic conditions. The test system is shown schematically. The cycle test has been completed on the evaporator for the 3000 KW steam generator. A complete operational history of the evaporator is given. Stress tests are continuing on a tee in the S2G system used to join to liquid metal streams of different temperatures. The work on nitriding of Be, 347 stainless steel and tool steel is complete; tables of corrosion rates of the three metals in liquid Na are presented. Methods of installing freeze seals and design of the seals are being investigated to prevent Na from being carried in the venting system of the S2G into the upper level reactor compartment. Radioactive lead experiments were continued.

- 2.350 AD 256511  
PROGRESS REPORT NO. 37 FOR OCTOBER AND NOVEMBER 1956  
Posey, W. J. (Ed.)  
(Mine Safety Appliances Co., Callery, Penn.) NP-6179, 60 p.  
(Dec. 13, 1956)

The operation of the 1000-kw heat transfer unit at high temperatures was demonstrated to aid development of components for such service and to add to the body of liquid metal technology, 3000-kw steam generator tests were made as part of a steam generator development. Research on liquid metal system components is reported. Thermal shock tests were made on a tee in the S2G system used to join two liquid metal streams of different temperatures. Experimentation in which results are evaluated by chemical or radiochemical techniques including experiments in the field of organics is reviewed. High velocity corrosion testing in biphenyl of reactor materials is reported.

- 2.350 NP-5751  
FINAL REPORT ON THE 1000 KW AIR COOLED, LIQUID METAL HEAT TRANSFER  
loop. R. A. Tidball, F. L. Mangold, S. N. Tower, and T. A. Ciarlariello.  
Aug. 16, 1955, 129p. Project NR-031-364. Contracts N9onr-85801 and  
NObs-65426, Technical Report No. 39.

A 1000-Kw liquid metal heat transfer system has been designed and operated at 1500°F. The system used sodium-potassium alloy to transmit heat from a gas fired furnace to an intermediate heat exchanger. Sodium was used to transmit the heat from the intermediate heat exchanger to an air heat sink. The maximum heat load on the system was 3,500,000 Btu/hr with the NaK temperature at the heater outlet of 1500°F. (See also NP-5491.)

- 2.350 NP-5601  
PROGRESS REPORT NO. 27 FOR FEBRUARY AND MARCH 1955. J. W. Mausteller,  
ed. Apr. 22, 1955. 62p. Contract NObs-65426.

Tests on the Mark B 3000-Kw steam generator are described, including a circulating cold trap and plugging indication, system cleaning, pump performance, NaK furnace tube failure, boiler water analysis, and heat transfer. Engineering studies are summarized on vent and drain line closures, NaK cross flow exchanger, development of EM pumps, pressure gages, wetting with alkali liquid metals, thermal shock, bellows testing, valve cleaning and testing, and thermal insulation tests in liquid Na. The depression of Na<sub>2</sub>O solubility in Na by K is discussed. Further studies on inhibition of mass transfer of radioactive stainless steel constituents in Na are described. The removal of residual radioactive Na with Na flushes was studied. Further results on radioactive leak contamination and the reactions of molten Zr in water are reported.

- 2.350 REPORT NO. 1 ON 1000 KW SYSTEM  
Tidball, R. A., F. L. Mangold and S. N. Tower  
Mine Safety Appliances Company, Callery, Penna.  
Memo Report No. 49, October 15, 1953. 14p.

The 1000-kw heat transfer system was designed to test pilot plant size liquid metal system components at temperatures to 1400°F. The test program was divided into phases: transferring heat to air and transferring heat to boiling water. Two liquid metal systems to prevent exposing the tubes of the liquid metal heater to full steam pressure in event of a failure of the steam generating equipment were used. The air cooled system is shown schematically. The NaK was circulated by a rotary magnet pump, through a flowmeter into the NaK heater. The discharge from the heater was piped to the tube side of the intermediate heat exchanger, and returned to the pump. Sodium was circulated by a DC conduction pump, through the flowmeter, the shell side of the intermediate heat exchanger, a swing check valve to the sodium cooler. Discharge of the sodium cooler passed through a stop valve, an a-c conduction pump to the suction of the d-c pump. The sodium was cooled by an air blast over finned tubes. Both NaK and sodium systems were fitted with diffusion type cold traps, expansion tanks, and emergency dump tanks. The sodium piping was fitted with tubular heaters (strapped to the outer surface) to preheat the piping before charging. Tests of the major components of this unit at various loads and temperatures are reported.

- 2.350 DESIGN AND OPERATION OF A SODIUM-TO-LITHIUM-TO-AIR HEAT-TRANSFER SYSTEM.  
A. R. Crocker, R. L. Potter, R. J. Spera, T. D. McLay, and S. H. Esleeck (Gen. Elec. Co., Cincinnati, O.).  
U. S. Atomic Energy Comm. TID-4500, 195 pp. (1954).

- 2.350 KAPL - M - HFK - 6 CA52-1696f  
OPERATION WITH LEAKS (OWL) TEST PROGRAM. Final Report. H.F. Karnes.  
Sept. 25, 1956. 41p.

The program included a series of studies designed to evaluate the possibility of operating a Na-cooled power plant after failure of one wall of a double-walled evaporator. Particular emphasis was placed on operation of an evaporator using NaK as a third fluid after failure of the NaK-boiling water heat transfer surface. The consequences to a Na system of a double-tube failure were also studied.

NSA 15:17746

- 2.350 ANL - 5060 (Del.)  
REACTOR ENGINEERING DIVISION QUARTERLY REPORT [FOR] MARCH 1, 1953  
THROUGH MAY 31, 1953. June 15, 1953. Decl. with deletions Jan.  
17, 1957. 157p.

Power Breeder Reactor. Conceptual design studies for the Power Breeder Reactor indicate the feasibility of a contained primary coolant system in a package arrangement. One- and two-group calculations are presented in detail for preliminary PBR estimations. A technique for impregnating  $UO_2$  with NaK has been developed. The resulting putty-type fuel was successfully extruded through a 3/8-in. hole. Data are presented on the fuel element design factors imposed by heat transfer and cooling limitations for fuel plates, pins, and spheres. Fission heat liberated in the PBR blanket was estimated to be 7.7% of the total core power. Design criteria resulting from this estimate are analyzed. Heat exchanger size for the transfer of 500 Mw of heat from Na to NaK has been calculated for the intermediate exchanger and for the NaK-to- $H_2O$  steam generator.

- 2.350 See Also: 2.210, 4.100, and 7.340

- 2.350 KAPL - M - JEZ - 1  
RECENT DEVELOPMENTS ON THE STANDBY COOLANT SYSTEM FOR THE WEST MILTON REACTOR. John E. Zerbe. June 20, 1949. Decl. Mar. 27, 1957. 12p.

The work done previously on the Standby Coolant System was reviewed in the light of more recent reactor designs and heat transfer data. It has been found that if a NaK-Na heat exchanger consisting of 16-1 $\frac{1}{4}$ " OD 60 mil wall stainless steel tubes is used, the thermal stress is reduced to approximately 22,000 psi when 2 $\frac{1}{2}$ % of 30 Mw is transferred under steady state conditions. Further calculations based on dissipating 2 $\frac{1}{2}$ % of 30 Mw have shown that the thermal stress is not influenced noticeably by the temperature rise in the NaK system. This is for both 80-20 (eutectic) NaK and 50-50 NaK. However, assuming the NaK-air exchanger is placed at a height of 55 feet the factor of safety for the various temperature rises in the NaK loops is different. Thus, for 80-20 NaK, if  $\Delta T_{NaK}$  equals 200 $^{\circ}$ F, calculations show that the exchanger must be at least 40 feet in the stack; for  $\Delta T_{NaK} = 150^{\circ}$  the exchanger must be located at about 86 feet. If 50-50 NaK were used, the factor of safety would be greater than with 80-20 NaK.

#### 2.400 EFFECT OF STRESS ON LIQUID METAL-CONTAINMENT INTERACTIONS

- 2.400 FTD-TT 61-31 (Transl.)  
INVESTIGATION OF HEAT RESISTANT ALLOYS, STRENGTH OF ALLOYS IN CONTACT WITH Na.  
S. T. Kishkin and G. P. Benedictova

The mechanical strength of a number of alloys operating in contact with Na was investigated... Results showed (for short term tests at 1000 $^{\circ}$ C) that Na-filled samples yielded negligible increase in U.T.S. and a decrease in plasticity of alloys. According to long-term test data the limit of long-time strength of alloys remained the same or increased. NSA 16:25720

#### 2.400 THE EFFECT OF MOLTEN METALS ON STRESSED SOLID METALS

W.A.Morgan, Murex Ltd. Review, V 2 no22, 1960, p. 62-75

Summary of the published work on the embrittlement of solid metals by lower melting point liquid metals. Some theories for this type of failure. 57 ref. (Q26s, 3-66, 2-66) (Hg, brazing alloys and solder)

- 2.400 Effect of 1200 F Sodium on Austenitic and Ferritic Steels  
Bi-Monthly Progress Report No. 1 for July and August 1959 on  
Thermal Shock, Nitriding, Stressed Corrosion, Unstressed Corrosion  
Mausteller, J. W. and Werner, R. C.  
MSA Research Corp., Callery, Pa.  
MSAR 59-99, Sept. 16, 1959, 22 p. Contract AT(11-1)-765

Completion of preliminary designs for a thermal shock loop, a corrosion loop, and a nitriding loop is reported. Stresses and unstressed corrosion studies are scheduled to be carried out in the same system. A literature search was started, and various sites were contacted to avoid duplication of effort. It was found that some work has been done at 1200 F sodium temperature with various oxygen concentrations, however, part of the data is not consistent. Test plans include corrosion testing of Croloy and stainless steel samples as well as similar and dissimilar welds of these materials in 1200 F sodium.

NSA 14:2695

- 2.400 "The Possible Mechanism for the Destruction of Stressed Metals Under the Influence of Liquid Metals," G. V. Karpenks, Tr. Seminara po Zharostockim Materialam, Akad. Nauk. Ukr. SSR Inst. Metallokeram. i Spets. Splavov, 1959 No. 4 79-85 (Pub. 1959).

A detailed literature survey is given. The most likely mechanisms seems to be the corrosive effect of liquid metals and the diffusion of liquid metals into the stressed metal lattice.

CA 57:148501

- 2.400 AD 255-358, Failure of Metals in Contact with Liquid Metals, Translation by WADD.

No abstract but contains: "Descriptions" Liquid metals, metals, failure, machines, stresses aluminum, mercury.

- 2.400 Effect of Sodium on the Mechanical Properties of Zirconium. J. C. Bokros. June 15, 1957. 39 p. (NAA-SR-1867)

Zr is useful as a structural material in nuclear reactors, and is employed in contact with high temperature liquid Na. It was found that surface oxide which develops on Zr in Na significantly lowers the fatigue life at elevated temperatures. Hydrogen on the other hand has very little effect on the fatigue life at elevated temperatures but lowers the fatigue life at room temperature. It was also found that exaggerated grain growth which occurs above 950° F in Zr severely reduces the fatigue life at elevated as well as low temperatures. The effect of Na, i.e., the pick-up of surface oxide and reasonable amounts of H<sub>2</sub>, does not significantly alter the tensile properties of Zr at high temperature. Data also indicate that Zr is stable to dimensional changes after thermal cycling.

- 2.400 TRANSIENT THERMAL STRESSES IN THIN-WALLED CYLINDERS. SIR MECHANICAL ENGINEERING ANALYSIS Jahsman, W. E. (Knolls Atomic Power Lab., Schenectady, N.Y.) KAPL-M-WEJ-3, 41 p. (Oct. 1956)

Using experimental data showing the time behavior of temperatures at various depths in the thin wall of a cylindrical pipe whose exterior is insulated and whose interior is repeatedly thermally shocked by a liquid Na stream, it is possible to predict the surface temperature transient analytically by representing it by a series of straight lines. Once the transient temperature distribution across the wall thickness is known, the time at which the surface temp. deviates most from the mean wall temp. can be obtained. The temp. distribution at this time of maximum deviation has importance because it can be used to determine the maximum surface thermal stress. Plasticity theory is used for the stress calculation because results by elastic theory show that maximum thermal stresses exceed the yield strength of the pipe material, AISI 347 stainless steel. Transforming the thermal strains associated with the calculated stresses into equivalent uniaxial strains, it is found that the thermal shock test results do not contradict any of the existing strain fatigue data for the material.

AD 256 511

- 2.400 KAPL-M-FJM-1 SUMMARY OF DUPLEX TUBE ANALYSES. F. J. Mehringer. Sept. 28, 1956. Includes Appendices A through G. 73p.

The heat transfer characteristics and stress levels in duplex tubes for heat exchangers are interdependent. The various studies of the heat transfer characteristics and stress analyses are summarized. The heat transfer characteristics discussed are those for boiling water, liquid metal, and metal-to-metal contact. Analyses have been made of the fabricating and operating stresses. As a result of these various analyses recommendations were made regarding material properties, tolerances and surface conditions of the tubular components, fabricating procedures, and operating precautions. Where areas of uncertainty still exist tests have been recommended. This information is significant to the SIG Test Steam Generator Program, since this steam generator is to have duplex heat exchanger tubes.



- 2.400 ATTACK OF UNSTRESSED METALS BY LIQUID MERCURY  
J. F. Strachan and N. L. Harris. J. Inst. Metals 85, 17-24 (1956)  
(Paper No. 1715)

The solubilities and wt. losses in the absence of air at room temperature of most of the metallic elements in static liquid Hg were detd., usually to 0.001%, by chem. analysis of the solns. and by weighing the specimens. The solubilities show a periodic relationship with the at. no., and there are indications that this can be related to the inner electronic shell structure. In general, the solubilities of the B sub-group elements exceed those of the true metals, while of this latter group the transition metals show the lowest values. When attack occurs, it involves wetting, surface amalgamation, soln, and occasionally combination and intergranular penetration. Oxidation brought some metals out of soln. in Hg and led to ambiguities. Exposure to air can result in a form of mass transfer. No significant changes occurred in the mechanical properties of Fe, Mo, some steels, and Ni alloys after 2000 hrs in Hg at 500°. Ni suffered a decrease in maximum stress, yield stress, and elongation of about 50%. Severe cavitation erosion of metals and alloys, normally resistant to Hg, occurred at room temperature on the application of 30 kc./sec. ultrasonic vibrations.

CA51-981h

- 2.400 PRELIMINARY STUDY OF THE FATIGUE OF METALS IN LIQUID METAL ENVIRONMENTS. J. W. Martin and G. C. Smith. Metallurgia 54, 227-32, 238(1956).

A series of expts. with 70/30 brass showed that amalgamation reduced the life at all stresses. The effect appears to be a min. in the region of the fatigue limit and increases rapidly as the stress amplitude is increased. In the amalgamated specimens, intergranular failure occurred over the whole of the fracture surface, although the zone wetted by Hg did not extend to the center of the fracture. In the case of 60/40 brass, specimens were fractured with and without Hg. In the fracture of an amalgamated specimen the path of the cracks tends to follow the  $\beta$ -matrix rather than run through the  $\alpha$ -phase, but in the nonamalgamated specimen the path of the fracture is random. The lower the fatigue stresses, the greater the depth of penetration of the Hg. Tests were run with mild steel in contact with liquid Sn and 18/8 stainless in contact with liquid Na. In the case of the mild steel, the fatigue limit is raised at elevated temp. and life is increased at stresses above the fatigue limit. In contact with liquid Sn, the fatigue limit is lowered and life at stresses above the fatigue limit is reduced. The proportional decrease in life is greatest at the higher stresses employed and least in the region of the fatigue limit. In the case of 18/8 stainless steel in contact with liquid Na, life does not seem significantly different from empty specimens, although a no. of cracks have been observed in specimens contg. Na. 11 references.

CA 51-998a

- 2.400 KAPL-M-EJP-2. Examination of the Forced Circulation Steam Generator from the Liquid Metal Heat Transfer Test Facility at Alplaus, N. Y. Report No. 2. Placzkowski, E. J. April 11, 1954. Changed from Official Use Only Oct. 8, 1956. 19p. Sub-Project No. 70: Investigation of Alplaus Units. Contract W-31-109-Eng-52.

The metallurgical investigation of the forced circulation steam generator revealed the failure of two Type 347 stainless steel tubes (air outside, mercury inside). The two tubes were located at the top of the unit and the failures occurred at the tube sheet welds (both "hot" and "cold" ends). The cracking was attributed to thermal cycling involving temperatures and stresses above the design values.

NSA 11:3789

- 2.400 See Also: 1.520, 4.140, 4.330, and 4.430.

2.400

NP-6646 UNCLASSIFIED

Cambridge Univ., England

The Effect of Stress on the Interactions Between Solid and Liquid Metals and Alloys. Interim Progress Report No. 2.

Morgan, W. A.

May 1951. 12p. Contract 13/5/165/226. (AERE-S/Pr-2087(May 1951)).

A series of experiments is presented for determining effects of molten metal penetration on the room-temperature mechanical properties of the pure metal. A similar series of experiments as above will be carried out, but the solid metal specimens will be stressed to varying extents during the heating in contact with the molten metal. Tensile testing to fracture of specimens at various temperatures and rates of loading while in the pure molten metal environment is reported. Fatigue testing is also reported. (W.L.H.)

2.400

RESULTS OF A KAPL THERMAL STRESS TEST ON A STAINLESS STEEL TUBE.

R. W. Lockhart and R. G. Kennison. Dec. 15, 1949. Decl. Mar. 9, 1957. 7p. (KAPL-M-RWL-5)

The effect of a repeating or cycling thermal stress on a thin wall stainless steel tube was determined. The apparatus used was essentially a paralleled flow single pass concentric tube heat exchanger with hot Na flowing through the inside of the inner tube and cold Na flowing in the annulus between the inner and outer tubes. It is concluded that the experimental values of Na film coefficients are about 35% lower than predicted but are of the right order of magnitude. A thermal stress varied from zero to 32,400 psi 132 times is insufficient to cause a crack or failure in a stainless steel tube at an average temperature of 540° F.

2.400

Be Thermal Stress Test. H. H. Winkler. Sept. 18, 1949. Decl. Feb. 9, 1956. 10 p. (KAPL-M-HHW-2)

Thermal stress tests were made on Be wafers in liquid Na for a period of 140 hr with  $\Delta t \sim 300^\circ\text{F}$ . A sampling of the wafers were metallographed, indicating Be cracks under high thermal stress.

2.400

KAPL-M-WW-2 Thermal Stress in a Beryllium Washer

Witzig, Warren F. and William A. Riemen

Knolls Atomic Power Lab., Schenectady, N. Y.

Contract W-31-109-Eng-52. July 1, 1949. Decl. Feb. 8, 1956. 17p.

Thermal stress was produced by a large radial heat flux in a Be washer immersed in a NaK alloy. After 7,000 cycles of thermal stress, the washer maintained its principle dimensions, but developed small radial cracks. There was a 2 mg. wt. gain despite obvious corrosion.



3.000

LIQUID METALS



### 3.100 SELECTED PROPERTIES

- 3.100 AD284165 Non Met Lab ASD WPAFB Lubrication in Space  
Enviroments by R. L. Adamezaek, R. J. Benging & H. Schivenker  
June 62 ASD TDR 62-541

Solid, semi-solid and liquid lubricants, hyd fluids, heat transfer fluids and novel lubrication techniques are discussed with respect to the current state of the art and the future capabilities of these various mat'ls. and/or their application. The severe environmental conditions of space are compared against both the current and future state of the art in the field of lubrication and energy transfer media. Research efforts currently being pursued by the Non Met Lab of ASD to provide new & improved lubricants are described. A brief interpolation is also given of the overall lubricant picture with respect to space technology in terms of reliability and system design.

- 3.100 AD 230-065  
SURVEILLANCE OF PROPERTIES OF INORGANIC ENERGY-CONVERSION AND  
HEAT-TRANSFER FLUIDS FOR SPACE APPLICATIONS  
W. D. Weatherford, Jr., Southwest Research Institute  
San Antonio, Texas, Notes on Conference on Properties of Alkali  
Metals at BMI, April 1961.

The properties of the condensed and vapor phases of Hg. Na, K, NaK are being studied to extend the coverage and of reappraising and revising the WADC Tech. Report 59-598.

- 3.100 Properties of Inorganic Energy-Conversion and Heat-Transfer  
Fluids for Space Applications  
Weatherford, W. D. Jr., Tyler, John C., and Ku, P. M. (Southwest  
Research Inst., San Antonio). Period covered: March 1960 to  
Nov. 1961. (WADD-TR-61-96) Contract AF 33(616)-7206. 470 p.

A properties handbook for various inorganic fluids which may have potential value as energy-conversion or heat-transfer fluids for space applications is presented. The fluids are given as three distinct classes: liquid metals, nonmetals, and gases. The liquid metals include mercury, cesium, rubidium, potassium NaK (78), sodium, lithium, bismuth, and lead. The nonmetals include aluminum bromide, sulfur, and lithium hydride. The gases include argon, helium, and hydrogen. Data are presented, where available, up to temperatures ranging from 2300° F for mercury to 4500° F for lead, and for pressures ranging from less than one atmosphere to greater than twenty atmospheres. The enumerated properties include vapor pressure, density, viscosity, surface tension, electrical resistivity, thermal conductivity, specific heat, latent heats, enthalpy-entropy relationships, melting point, critical properties, dielectric constant, ionization potential, magnetic susceptibility, thermal neutron cross sections, and corrosion characteristics. The characteristics of the various fluids are discussed, and the recommended values for the fluid properties are presented in either tabular or graphical form, or both, with detailed documentation as to basis and source. In addition, background material, including thermodynamic-cycle, heat-transfer, compatibility, and working fluid considerations is discussed. A summary of current research activities in this field is presented. NSA 16:5088

- 3.100 BNL-661, Table of Reactor Coolant Properties, Green, Leon,  
March 10, 1961

Selected properties of coolants currently being considered for use in nuclear reactors are presented. Physical, chemical, and nuclear properties that must be considered in selecting reactor coolants are listed. Data on cost, material compatibility, toxicity, non-nuclear hazards are also given. A number of combined parameters were evaluated that are helpful in comparing such important criteria as low pampering power, wide temperature range, low induced activity, and moderating properties. Included is a bibliography listing references to additional data.

- 3.100 Critical Properties of the Alkali Metals.  
Dr. Louis Rosenblum, NASA-Lewis Research Center  
BMI Conf. on Alkali Metals, April 1961.

Results to date on Na.

- 3.100 Beechcroft, R. I., C. A. Swenson, "An Experimental Equation of State of Sodium," Phys & Chem of Solids 18, 329-344 (March 1961)

An equation was obtained for pressures to 20,000 atm. and from 20°K to the mp. Various experimental details are given of an apparatus with which it is possible to obtain pressure-volume data which are reliable to  $\pm 0.002$  in  $\Delta V/V_0$  over this range of temperature and pressure. The equation of state can be represented to within the above accuracy by an expression which is derived from the assumption that the isothermal compressibility is linear with volume and has no explicit temperature dependence. A discussion is given to the effect of these assumptions on the validity of calculations of the variation with volume of the temperature dependent contribution to the thermodynamic functions. Gruneisen constants as obtained from various definitions are calculated as functions of temperature and volume, and the validity of the Mie-Gruneisen equation of state as it applies to Na appears open to question below room temperature. Recent high pressure ultrasonic experiments on Na are interpreted as being in agreement with this conclusion.

- 3.100 N62-1577  
HYDROMAGNETIC EQUILIBRIUM EXPERIMENTS WITH LIQUID AND SOLID SODIUM  
Lawrence Radiation Lab., Univ. of Calif., Livermore  
Colgate, S. A., Furch, H. P., and Halliday, F. O.  
In National Research Council, Magneto-Fluid Dynamics.  
Proc. of a Symposium sponsored by IUTAM/NAS-NRC, Williamsburg, Va. and Washington, D. C., Jan. 1960. Repr. from Rev. Modern Phys., v. 32, no. 4, Oct. 1960. p. 744-47. 7 refs. (See N62-15768 15-21. (Sponsored by AEC)

In a homogeneous field varying in time, the magnetic moment of the particle is constant in the first approximation. Expression for the variation of the moment and for the shift of the center of motion in higher approximations are derived. In a constant inhomogeneous field, the secular drift in the constant moment approximation has been given by Alfven and Spitzer. For a few simple field configurations, higher approximations for the drift have been derived.

- 3.100 Liquid Metal Cooled Reactors. H. Chilton.  
Electrical Review, July 8, 1960, p. 47-52

Use of various metals (Na, K, Li, Hg, Bi and Pb) as coolants in experimental reactors. Engineering consideration. Coolant properties. Design and operation data for a Na-cooled reactor. Use of stainless steel and low-alloy Cr-Mo ferritic steel as liquid Na-container material. Container design.

- 3.100 Liquid Metals  
Evans, J. W.  
United Kingdom Atomic Energy Authority, Culcheth,  
Lance, England  
Nuclear Eng. 4, 59-63 (1959) Feb.

The properties and individual characteristics of the liquid metals (Hg, Bi, Na, and Na-K) suitable for reactor coolants are presented.

NSA 13:7817

- 3.100 Selected Values of the Physical Properties of Various Materials.  
F. J. Tebo (Argonne Natl. Lab., Lemont, Ill.). U. S. Atomic  
Energy Comm. ANL-5914, 255 pp. (1958).--

Thermal cond., sp. heat, d., viscosity, and Prandtl no. are given  
as a function of temp. for materials of interest in nuclear-reactor heat-  
transfer and fluid-flow analysis. CA 53-889h

- 3.100 Willibald Machu (Universitate Cairo)  
Material and Corrosion Problems in the Reactor with Liquid Metals  
as Coolant  
Atomkern-Energie 3, 141-4 (1958) April (in German)

The last part in a series on material and corrosion problems in  
liquid metal cooled reactors is presented. The behavior of reactor materials  
in liquid bismuth, lead, and mercury is described. The corrosion mechanism  
of liquid metals is briefly discussed.

NSA 12:10093

- 3.100 Materials for Liquid Metal Systems  
Holman, William  
American Standard, Atomic Energy Div., Redwood City, Cal.  
ASAE-26  
Oct. 28, 1957, 32 p.

(Lecture presented at the Atomic Industrial Forum's Third Course  
on Reactor Materials, Stanford University, Stanford, Calif.,  
July 9-19, 1957.

A review of progress in the use of liquid metals is presented. A  
number of liquid metals are compared, and the general problems of selecting  
container materials are considered. In addition, a discussion of corrosion  
mechanisms and corrosion testing methods commonly employed are examined as  
well as problems encountered with liquid metals of greatest interest. (J.R.D.)

NSA 13:11820

- 3.100 Liquid Metals Technology, Part 1. Chemical Engineering Progress  
Symposium Series, v. 53, No. 20, 1957. 84 pages. (Published  
by American Institute of Chemical Engineers)  
Articles abstracted separately. Metals Review Page 20,  
March 1958
- 3.100 FXM-2210 Materials Survey For PWAR-6 Design, L. M. Raring (P&WA Div.  
UAC, Middletown, Conn.) October 17, 1956.

Properties data for PWAR-6 reactor materials are listed. Data are  
included for Inconel, salt, Na, NaK, thermal insulation, alkylbenzene and Pb.

NSA 16: 15901

- 3.100 APPLIED MAGNETIC HYDRODYNAMICS  
Translated from Trans. of the Inst. of Physics, Academy of Sciences,  
Latvian S.S.R., Riga, 1956, 142p. OTS.

The papers included in this volume are: magnetic hydrodynamic  
phenomena in liquid metals; electrodynamic pumps for liquid metals; theory  
of induction pumps, and others. (NP-tr-355)

NSA 14:12292

- 3.100 ORNL-360  
A DISCUSSION OF LIQUID METALS AS PILE COOLANTS, A. S. Kitzes.  
Aug. 10, 1949. Dec. 1. Jan. 5, 1956. 41p. Contract W-7405-eng-26.

Criteria given for evaluating liquid metal coolants are corrosion,  
nuclear properties, availability, and cost, radiation stability, heat-transfer  
properties, and health hazards. Lithium, Na, NaK, Pb-Bi, and Ga were considered  
as the liquid metals most suitable to be studied as coolants.



- 3.100 LIQUID-METAL REACTOR DEVELOPMENTS  
R. W. Dickenson (AI)(TID-7623 (p 97-104))

The development programs to reduce cost and increase the reliability of Na-cooled reactor systems are discussed. The programs have produced important technical advances in Na technology at temperatures up to 1050°F and these advances are discussed.

NSA 16:28554

- 3.100 Final Summary Report of Development Work for the Department of the Navy. W. Markert, Jr. and J. J. Owens. July 24, 1952  
44 p. Contract Nobs-34222. (NP-4189; BW-5060; ES-401).

Work on Na-K alloy, including development of equipment, procedures, and other information for use in heat-transfer systems, has been carried on under this contract over the period June 1946 through June 30, 1952. Physical properties of Na-K alloys, galvanic action and thermoelectric potentials between dissimilar metals in Na-K, and corrosion of materials in static and dynamic Na-K systems were investigated. A large heat-transfer apparatus (described in report BW-5217, reference No. 133) was designed to determine the heat-transfer and friction factors for gases in forced flow over tubes for Reynolds number up to 400,000. Also a part of this contract in the initial stages was the design of a pressure vessel and investigation of related problems for a water system. This final report summarizes the work conducted and includes a complete title listing of the 65 reports issued during the course of the work.

- 3.100 Liquid Metals and Nuclear Power  
Boadle, C. D. (Rolls-Royce Ltd., Derby)  
Atomics 8, 41-5 (1957). Feb.

A survey is given of the use of liquid metals as a means of high-temperature heat extraction from nuclear reactors. Data are included on the physical and nuclear properties of the various metals considered, such as Li, Na, K, Hg, Pb, Bi and their alloys. Typical diagrams are given for liquid metal cooled reactors. NSA 11:4695

- 3.100 Sodium, (Na) Data Sheet-D.10. Apr. 14, 1955. 15 p.  
(AERE-ED/D-10 (Issue 2))

A brief report on the procurement, chemical, nuclear, and physical properties of sodium is presented, together with charts on temperature-corrosion and resistance of materials at 300 and 600°C.

- 3.100 The Correlation of Physical-Chemical Constants of Halides of Alkali Metals by Gertsriken, S. D.  
Voprosy Fiz. Metal. i Metalloved., Akad. Nauk Ukrain. S.S.R., Sbornik Nauch. Rabot 1955, No. 6, 77-81.

The different values of phys. chem. constants of halides of alkali metals....

- 3.100 Liquid Metals Handbook; Sodium-NaK Supplement.  
Carey B. Jackson, ed.-in-chief. June 1955. 445 p.  
(TID-5277; NAVEXOS-P-733). \$2.00 (GPO); Dept.

This edition of the Liquid Metals Handbook (TID-5277; NAVEXOS-P-733) is devoted entirely to Na and NaK. Fifty authors have contributed material. Aspects of heat transfer treated include natural circulation, forced circulation, boiling, and condensation. System design and component chapters include thermal stress, piping considerations, thermal insulation, heat exchangers and steam generators, heating, and cooling. Applications of Na and NaK technology to the Genie project, the Mine Safety Appliances high-temperature system, and the Experimental Breeder Reactor are described.

- 3.100 PROPERTIES OF LIQUID METAL COOLANTS  
R. D. Brooks, KAPL  
The Reactor Handbook, Vol. 2 Engineering, Ch 2.2 p. 253-76. 1955  
  
Covers Hg, K, Na, and NaK. (5 references)

- 3.100 THE REACTOR HANDBOOK, VOL 2. ENGINEERING. J. F. Hogerton and  
R. C. Grass, eds. [Sept. 1953]. Decl. with deletions May. 1955.  
[Issued] May 1955. 1083p. (AECD-3646). \$5.50(GPO); Dep.

Various phases of reactor engineering are discussed, specifically light-and heavy-water-cooled systems, liquid-metal-cooled systems, gas-cooled systems, aqueous fuel systems, liquid-metal fuel systems, fused-salt systems, handling and control, and reactor designs.

- 3.100 Liquid-Metals Handbook. Richard N. Lyon, ed. June 1952.  
276 p. (NAVEXOS-P-733 (Rev.)). \$1.25 (GPO); Dep.

This second edition of the liquid-Metals Handbook incorporates suggested improvements and additional releasable data. It offers a reasonably complete compilation of information on liquid metals covering the physical properties, industrial utilization, corrosive effects on materials, heat transfer properties, heat transfer systems, heat transfer system components, and availability for production of low-melting-point alloys.

- 3.100 AERE-ED/D-10 (Issue 2)  
Great Britain Atomic Energy Research Establishment, Harwell, Berks,  
England Sodium, (Na). Data Sheet-D. 10. April 14, 1955.

A brief report on the procurement, chemical, nuclear, and physical properties of sodium is presented, together with charts on temperature-corrosion and resistance of materials at 300 and 600°C.

NSA 11:5758

- 3.100 The Measurement of the Physical and Chemical Properties of the Sodium Potassium Alloy  
Ewing, C. T. and Miller, R. R.  
Naval Research Laboratory, Washington, D.C.  
Quarterly Progress Report No. 1, Report P-3010  
30 September 1946, 74 p. PB 129 268  
U.S. Govt. Res. Repts. 32, P. 26

The alloys of potassium-sodium are under a study as a heat transfer medium. Physical and chemical properties, along with measurements of heat transfer coefficients on an engineering scale, are being studied. This report is concerned more with the description of apparatus and methods than with measured results; however, preliminary measurements on density and viscosity are included.

---

### 3.110 GENERAL PHYSICAL PROPERTIES

- 3.110 HALL COEFFICIENTS OF LIQUID METALS  
A. J. Greenfield (Univ. of Chicago). Phys. Letters, 3:121-2  
(Dec. 15, 1962). (In English)

A very accurate experimental technique is described for the measurement of the Hall coefficients of liquid metals. Measurements having an error factor of 4 less than that of previous work have been made on Hg, In, Tl, and Pb. For Hg and In, the measured Hall coefficient is equal to the free electron value, or the value obtained from the electron concentration equal to the atomic concentration times the valency, 2 for Hg and 3 for In. For Tl and Pb, the measured Hall coefficient is about 18 and 32% smaller than the respective free electron values, corresponding to a valency of 3 for Tl and 4 for Pb.

NSA 17:8852

- 3.110 BNL-756  
ALKALI METAL PHYSICAL PROPERTIES PROGRAM AT P&W AIRCRAFT - CANEL  
R. E. Cleary and S. M. Kapelner  
Second Annual High Temperature Liquid Metal Heat Transfer Meeting,  
Brookhaven National Lab., May 17, 1962

Program review presented on the physical properties program on alkali metals and NaK in progress at CANEL. The data reported to date included electrical resistivity data (also in PWAC-349), and thermal conductivity up to 865°C. Effort was continued to extend the latter data to higher temperatures (1300°C for Li) and to continue other physical property measurements including viscosity, vapor pressure, vapor density and wetting characteristics.

- 3.110 BNL-756  
ENGINEERING PROPERTIES OF POTASSIUM  
Joseph F. Walling, B.M.I.  
Second Annual High Temperature Liquid Metal Heat Transfer Meeting,  
Brookhaven National Lab., May 17, 1962.

Current status on the research program on thermodynamic and physical properties of vapor and liquid phases of potassium. The data available was presented, including vapor pressures, liquid viscosity and heat contents at temperatures to 2100°F. The purity of the potassium is discussed, and the initial data represents properties of K containing 50 ppm oxygen or less.

- 3.110 THE EXPERIMENTAL DETERMINATION OF THE THERMOELECTRIC POWER IN LIQUID METALS AND ALLOYS  
C. C. Bradky (Royal Society Mond Lab., Cambridge Eng.)  
Phil. Mag. (8), 7:1337-47 (August 1962)

The thermoelectric power in the liquid state was measured as a function of temperature for 10 pure metals and nine NaK and RbK alloys. (includes Na, K, Rb, Hg)

NSA 17:1979

- 3.110 COMPRESSIBILITY OF LIQUID SODIUM-POTASSIUM ALLOYS  
G. Abowitz and R. B. Gordon (Yale Univ., New Haven)  
J. Chem. Phys. 37:125-8 (July 1, 1962)

The velocity of sound was measured in the NaK system as a function of both composition and temperature. For each composition the velocity was found to be a linear function of the temperature. The behavior of the compressibility, because of the volume contraction on alloying, cannot be explained in terms of a free electron model. A possible explanation is that changes in the electronic charge density upon alloying give rise to the volume contraction and the slight positive deviation in the compressibility.

NSA 16:29406

- 3.110 "Compressibility of NaK Alloys," by G. Aborvity and R. B. Gordon (Yale) J. Chem. Phys. 37:125-8, July 1, 1962.

The velocity of sound was measured in NaK system as a function of both composition and temperature. For each composition, the velocity was found to be a linear function of temperature. The behavior of the compressibility, because of the volume contraction ( $-\Delta V$ ) on alloying cannot be explained in terms of free electron model. A possible explanation is that changes in the electronic charge density upon alloying gives rise to the volume contraction and slight positive deviation in the compressibility.

NSA 16:29604

- 3.110 NP-11671  
ENG. PROP. OF K  
Quarterly No. 6, Jan. 1 thru Mar. 31, 1962, A. W. Lemmon, (BMI)  
Columbus, April 30, 1962, Cont. NAS 5-584, 18 p.

Continuation of prop. study.

NSA 16:21039

- 3.110 BMI Report to AEC-NASA  
LIQUID METAL CORROSION MEETING, DECEMBER 1961 at BNL

Engineering properties of potassium to 2100°F, analysis of  
Cb-12r included. TID-7626 (P.1) (AGN 2-2786)

- 3.110 TIM-65, PROPERTIES OF LIQUID METALS MELTING BELOW 1000°F  
H. C. Hopkins P & WA Div. VAC, Hartford, Conn., Grt 5, '54,  
Contract AT(11-1)-229

Graphs are presented of the following properties of liquid metals  
melting below 1000°F. V.P., density, heat capacity, viscosity, thermal  
conduct and elect. resist. NSA 16:19370

- 3.110 Structure and Properties of Liquid Metals. A. A. Vertman &  
A. M. Samakin, Tr. Inst. Met. im. A. A. Barkova, 1962  
No. 10 108-34. A Review of 159 references.  
CA 57:14840

- 3.110 NP-11088  
ENG. PROP. OF K  
4th Quarterly, by A. M. Lemmon, BMI, Oct. 30, 1961

Report describes equipment for obtaining properties, e.g., for  
B.P.: vapor pressure; specific heat, viscosity, development of equipment  
and procedures for purification, enthalpy, thermal conductivity.

NSA 16:4534

- 3.110 SUPERCONDUCTING PROPERTIES OF THE TWO MODIFICATIONS OF MERCURY  
C. A. Swenson and J. E. Schirber (Ames Lab)  
p. 338-45 of "Proceedings of the VIIth International Conference  
on Low Temperature Physics," G. M. Graham and A. C. Hollis Hallet, eds.  
Toronto, Univ. of Toronto Press, 1961 (IS-195)

Data obtained on the physical properties of  $\beta$  Hg are given in  
comparison with  $\alpha$  Hg and Ta. The data includes precise critical field  
measurements at 0 pressure, as well as the change in critical field for a  
given temperature with pressures up to 3000 atm. The data are analyzed  
thermodynamically and discussed.

NSA 15:13536

- 3.110 THE TEMPERATURE RANGE OF LIQUID METALS AND AN ESTIMATE OF THEIR  
CRITICAL CONSTANTS, A. V. Grosse, J. Inorg. and Nuc. Chem.,  
22:23-31 (Dec. 1961)

Includes estimate of critical temperature, pressure and density  
of various liquid metals, e.g., Na, Pb, and Sn.

NSA 16:11632

- 3.110 LOW-TEMPERATURE TRANSPORT PROPERTIES OF THE ALKALI METALS II.  
THE TRANSPORT COEFFICIENTS  
J. G. Collins and J. M. Ziman (Cambridge Univ., Eng.) Proc. Roy.  
Soc. (London), A264:60-87 (Oct 24, 1961)

. . . the transport coefficients are consistant with a Fermi  
surface which is distorted in Li, becomes nearly spherical in Na and K, and  
is again distorted in Rb and Cs.

NSA 16:2367

- 3.110 LOW-TEMPERATURE TRANSPORT PROPERTIES OF THE ALKALI METALS. I.  
THE ELECTRON-PHONON INTERACTION  
J. G. Collins (Cambridge Univ. Eng.) Proc. Roy-Soc. (London),  
A263. 531-44 (Oct. 10, 1961)

. . . calculations of the resistivities of metals, and of the phonon drag contribution to the thermoelectric power.

NSA 16:619

- 3.110 COOLING BY LIQUID METALS. PROBLEMS OF COMPATIBILITY  
R. Darras (Commissariat a l'Energie Atomique, (Paris)).  
Energie Nucleaire (France), 3:128-38 (Mar - Apr 1961)  
(In French)

The properties of liquid metals as coolants are reviewed; corrosion and structural problems encountered in the use of these liquid metals are discussed. Purification and oxygen content control are considered, especially in the case of Na and NaK.

NSA 15:19904

- 3.110 SELF-DIFFUSION OF LIQUID MERCURY  
Robert E. Meyer (ORNL). J. Phys. Chem., 65:567-8 (Mar 1961)

Self-diffusion measurements were made, using the capillary-reservoir technique, to check the temperature dependence of the diffusion coefficient over a wide temperature range. The results indicate that the Stokes-Einstein and Eyring expressions are favored for diffusion coefficient values. Convection error at high temperature shows more effect in other equations.

NSA 15:12945

- 3.110 AD-230-085 Div. 14  
(5 Jan 60)  
Southwest Research Inst. (San Antonio, Tex.)  
PROPERTIES OF INORGANIC WORKING FLUIDS AND COOLANTS  
FOR SPACE APPLICATIONS, by W. D. Weatherford Jr., John C. Tyler,  
and P. M. Ku, Pet. on Aviation Lubricants.  
Dec. 59, 1v. incl. illus. tables (WADC Technical rept. no. 50-598)  
(Contract AF 33(616)6232) Unclassified report  
Also see WADD-TR-61-96 Nov. 1961  
Descriptors: Coolants\*; Space flight; Inorganic substances; Liquid  
metals; Liquids; Gases; Hydraulic fluids\*; Physical properties;  
Chemical properties; Handbooks; Thermodynamics; Temperature; Heat  
Transfer; Lubricants\*.

This report is intended to serve as a properties handbook for various inorganic fluids which may have potential value as coolants or working fluids for space applications. The fluids are presented as three distinct classes - namely, liquid metals, liquid nonmetals, and gases. The liquid metals include mercury, cesium, rubidium, potassium, sodium, and lithium. The liquid nonmetals include sulfur, phosphorus, and aluminum bromide. The gases include krypton, argon, helium, hydrogen, and aluminum chloride. Data are presented, where available, for temperatures ranging from less than 600°F to greater than 2500°F, and for pressures ranging from one atmosphere to greater than twenty atmospheres. The enumerated properties include density, viscosity, thermal conductivity, specific heat, latent heats of fusion and vaporization, enthalpy, entropy, vapor pressure, critical properties, diffusion coefficients, surface tension, thermal neutron absorption and scattering cross sections, equilibrium species composition, ionization potential, dielectric constant, resistivity, magnetic susceptibility, and materials compatibility. The characteristics of the various fluids are discussed and the recommended values for the fluid properties are presented in either tabular or graphical form, or both, with documentation as to source. In addition, background material such as thermodynamic-cycle, heat transfer, and compatibility considerations are discussed. General and specific recommendations for future research are also presented. (Author)

3.110 STRUCTURE OF LIQUID METALS  
(TID-11882)

R. B. Gordon (Yale Univ., New Haven) Mar 1, 1961

The compressibilities of NaK were measured and found to be slightly greater than the weighted average of the compressibilities of pure components. The deviation is in the opposite direction to that predicted by free-electron theory and must be explained in terms of charge transfer effects.

NSA 15:13357

3.110 Alkali Metals Program

A. J. Glassmen, NASA-Lewis Research Center  
BMI Conf. on Alkali Metals - April, 1961

The physical and thermodynamic properties of Na and K with respect to eight fluid system components.

3.110 Freedman, J. R. & Robertson, W., Electrical Resistivity of Liquid Sodium, Liquid Lithium, and Dilute Liquid Sodium Solutions,  
Journal of Chemical Physics 34, 769-80 (March 1961).

The three factors of atomic size, ion core potential, and charge, which contribute to the increment in electrical resistivity produced by solutes in metallic solutions, were separated and experimentally evaluated in liquid sodium. The results may be expressed in a semi-empirical relation defining the increment in resistivity of a monovalent solution,  $\Delta P = 0.063 \Delta \text{Atomic Number} + 0.53 (\Delta V/V)^2$ ,  $\mu \text{ ohm cm/at. \%}$ , where  $\Delta V/V$  is the fractional difference in atomic volume of solute and solvent and the first term involves the absolute value of the difference in atomic number of sodium and the solutes lithium, potassium, cesium, rubidium, silver, and gold.

3.110 TID 07623, Proceedings of Symposium on Na Reactors Technique, May 24-25, 1961.

The history and present status of liquid metal cooled reactors particularly Na are discussed. Compares the several properties of gas, liquid, and liquid metals.

NSA 16:28545

3.110 Liquid Metal Cavitation Problems and Desired Research

Hammit, Frederick G.  
American Society of Mechanical Engineers, Paper No. 60-HYD-13, 1960, 7p. Rev. of Met. Lit. 17:5

Cavitation of liquid Na, K, Rb, Na-K alloys, Hg, Bi and Pb-Bi alloys as heat-engine fluids versus  $H_2O$ . Temperature, density of liquid, density of vapor, viscosity, surface tension, heat capacity latent heat, thermal conductivity, vapor pressure and bulk modulus. (R2m, 14-60, Hg, Na, Na-b, Bi, Pb-b).

3.110 Liquid-Metal Corrosion Research (P&W Canel)  
K. J. Kelly, NASA TN-D-769, 1960

Electrical resistivities of NaK, gas chromatography for analysis of impurities in Helium cover gas.

NSA 15:13273

3.110 (AEC tr 4879) Structure and Properties of Liquid Metals  
(Stroenie i Svoistva Ghidkikh Metallov)  
A. M. Samarin, ed (Akademiya Nauk SSSR Metallurgicheskoi Institut im. A. A. Barkova) 1960

A compilation of reports on structure and properties of liquid metals is presented.

NSA 16:19377

- 3.110 THE APPLICATION OF THE THEORY OF THERMODYNAMIC SIMILARITY TO THE DETERMINATION OF PHYSICAL PROPERTIES OF LIQUID METALS  
G. F. Butenko and M. I. Radchenko. Inzhener - Fiz. Ahur, A Kud. Nauk Belarus. S.S.R. 3 No. 6. 66-71 (1960) June (In Russian)

It is shown that the Lorents function of fused metals can be expressed by an equation. Results of calculations are compared with experimental data.

NSA 14:20320

- 3.110 THERMOPHYSICAL PROPERTIES OF SUBSTANCES  
(Teplofizicheskie Svoista Veshchestv) I.I. Ayzenshtat, ed.  
Translated from a publication of the Printing House of State Publishing House for Power Engineering, Moscow. 479p. OTS (NP-tr-343)

The physical properties of various gases, liquids, organics, and liquid metal are tabulated.

NSA: 14:8761

- 3.110 Effect of a Longitudinal Magnetic Field on Pipe Flow of Mercury. Samuel Globe. ASME Publication, Paper no. 60-WA-192, 1960, 9 p.

Effect of an axial magnetic field on transition from laminar to turbulent flow and on the turbulent friction factor for flow of Hg in pipes of glass and Al. Data are given for maximum Hartmann number, pressure gradient, velocity of flow and Transition Reynolds number. 20 ref. Transport of Hg.

- 3.110 LUBRICATION BEHAVIOR OF LIQUID METALS  
Period Covered: July 1958 through Sept. 1959 (WADC-TR-59-764)  
Patrick H. McDonald (North Carolina State College, Raleigh, N.C.)  
Jan 15, 1960. 77p. Project No. 7022. Contract AF 33(616)-5885. OTS.

The lubricating behavior of liquid metals in two categories, hydrodynamic and boundary lubrication is described (more on abstract).

NSA 15:6081

- 3.110 THE TRUE SPECIFIC HEATS OF URANIUM, THORIUM, AND OF OTHER METALS  
E. A. Mit'kina  
Atomnaya Energ. 7, 163-5(1959)  
Aug. (In Russian)

The true specific heat of Na is included and was determined by a cooling-heating method and by the absolute method using an electron-radiative calorimeter. The design of the calorimeter is presented, and the obtained results and previously published data are tabulated.

NSA 13:20208

- 3.110 TID 3544  
THE SUPPRESSION OF TURBULENCE IN PIPE FLOW OF MERCURY BY AN AXIAL MAGNETIC FIELD. Samuel Globe. p.68-79 of "1959 Heat Transfer and Fluid Mechanics Institute," Stanford, Calif., Stanford Univ. Press, 1959. 250p. NSA 13:22863.

- 3.110 Crystal Structure of Beta-Hg. Masao Atoji, J. E. Schirber, and C. A. Swenson (Iowa State Univ., Ames)  
J. Chem. Phys. 31, 1628-9 (1959) Dec.

The crystal structure of Beta-Hg, was determined, and compared to alpha-Hg according to Pauling's resonating valance bond theory of metals.

NSA 14:5607

- 3.110 Venkateswarlu, K. et al.  
Annamalai Univ., Annamalainagar, South India  
Magnetic Susceptibility of Alkali Elements, Part II. Liquid  
Alloys of Sodium and Potassium, June 1958.

Alloys of sodium and potassium were prepared in vacuum in a specially blown pyrex glass apparatus. Several bulbs containing these alloys of different compositions have been studied at temperatures ranging from 30 to 250 degrees C. The compositions of these alloys have been determined by gravimetric method. The results show that for the alloys of all compositions the additivity law is obeyed both at room temperature and at high temperatures. No evidence for the formation of the compound  $\text{Na}_2\text{K}$  could be detected from the magnetic study. NSA 12:14004

- 3.110 AD 153 159  
Measurement of the Effect of an Axial Magnetic Field on the Reynolds  
Number of Transition in Mercury Flowing Through a Glass Tube  
Bader, Michel and Carlson, William C. A.  
National Advisory Committee for Aeronautics,  
Washington, D. C.

May 58, 8p. incl. illus.  
TAB No. U59-9, 1 May 1959, p. 2040

Experiments were conducted to determine the effect of a 15,000 gauss axial magnetic field on the flow of mercury through a glass tube of 0.027 in. inside diam. It was found that when only slight instabilities were present by Reynolds numbers from 5,000 to 8,000, the Reynolds number of transition could be increased by as much as 10 percent.

- 3.110 Blatt, F. J. (Michigan State Univ., East Lansing)  
The Magnetic Susceptibility of Metals. August 1958

Factors affecting the magnetic susceptibility of metals, and particularly of alkali and noble metals, are discussed. Data are tabulated on the susceptibilities of lithium and sodium. NSA 12:17244

- 3:110 FREE THERMAL CONVECTION IN MERCURY IN A CLOSED CIRCULAR TUBE IN A  
TRANSVERSE MAGNETIC FIELD  
Smirnov, A. G.  
Zhur. Tekhn. Fiziki (in Russian), 28:1549-1555 (1958)

Liq. Hg was enclosed in a glass tube inclined at  $10^\circ$  from vertical. Heat was transmitted from the upper to the lower end, and the effect of a transverse magnetic field  $H = 70\text{-}7000$  gauss on the free thermal convection was studied for the case (a) when the direction of  $H$  was  $\perp$  the plane,  $S$ , separating the upward and downward convection currents, and for the case (b) when the direction of  $H$  was  $\parallel S$ . In weak  $H$  ( $<110$  gauss in case a, and  $<300$  gauss in case b) the temp. gradient  $\propto H^2$ ; in strong  $H$  it increased linearly until a certain critical value - dependent on the heat input - was reached, when further increase of  $H$  did not cause any variation of the temp. gradient. At this stage the laminar convection is entirely suppressed. Thus, the appn. of a sufficiently strong transverse  $H$  to the portion of the tube characterized by laminar convection produces a "retarding" effect both in the hydrodynamic and in the thermal sense, since the flow of the liquid in this portion of the tube practically ceases and the total heat flow in the tube is decreased. Appn. of the magnetic field to the portion of the tube in which heat is transferred by conduction has no effect on the temp. distribution, neither in this nor in other portions. -- M.H.S.

MA26:361

- 3.110 Manufacture and Availability of the Alkali Metals.  
M. Sittig, Ethyl Corporation, AIChE No. 20, Vol 53, 1957,  
Liquid Metals Tech. (Part 1)

Manufacturing processes for various liquid metals and a comparison of thermochemical and electrolytic processes for Na and K. AGN Lib. C-1 3-689.





- 3.110 The Magnetic Susceptibility of Alkali Metals  
Appel, J. (OSRAM Soc., Augsburg, Ger.)  
Z. Naturforsch. 11a, 613-15 (1956).

The magnetic susceptibility is calculated theoretically by combining the paramagnetic spin contribution, the diamagnetic ion contribution, and the contribution due to valence electrons. CA 51:7080

- 3.110 Thermal and Electrical Conductivities of the Alkali Metals at Low Temperatures. MacDonald, D.K.C., G. K. White and S. B. Woods  
Proc. Roy. Soc. (London) A235, 358-74 (1956).

The thermal and electrical conductivities of very pure Li, Na, K, Rb, and Cs were measured down to 2°K. The theoretical relations that exist between the low-temperature "ideal" resistivities and those at higher temperatures are discussed. 47 references are given. CA 50:15147

- 3.110 Self-Diffusion in Liquid Mercury  
Norman H. Nachtrieb and Jean Petit (Univ. of Chicago).  
J. Chem. Phys. 24, 746-50 (1956).

Self-diffusion in liquid Hg was detd. by a shear-cell method. At atm. pressure  $D = 8.5 \times 10^{-5} \exp(-1005/RT)$  sq. cm./sec. from 0° to 98°. At 30° for pressures ranging up to 8366 kg./sq. cm.,  $\log D = (-0.572 - T_m/T) - 4.348$ , or  $\log D = -4.7889 + 9.637 \times 10^{-6} P$  (kg./sq. cm.). The activation vol. is 0.587 cc. The pressure dependences of viscosity and diffusivity are identical within exptl. error, but the temp. variations are not equal. The results are discussed in terms of an imperfect crystal lattice model of a liquid. CA 50-9811b

- 3.110 Interatomic Potential Functions of Sodium and Potassium  
Ling, Rufus C.  
J. Chem. Phys. 25, No. 4, 609-13 (1956).

The liquid structure theory of Born and Green is used to interpret X-ray diffraction measurements on liquid sodium and potassium to find an effective interatomic potential function for pairs of sodium and pairs of potassium atoms. This potential function predicts approximately the correct binding energy for solid sodium and potassium, and when reinserted in the X-ray formulas predict scattering curves at higher temperatures which are in good agreement with experiments.

- 3.110 X-Ray Scattering by Liquid Metal Alloys (A Kinetic Approach)  
Ling, R. C.  
J. Chem. Phys. 25, No. 4, 614-616 (1956)

The Born-Green theory of liquids is extended to the case of liquid mixtures and a formula for the X-ray scattering by such liquids is developed. The formula is used to calculate the X-ray scattering by a liquid sodium-potassium alloy, and fair agreement with the experimental scattering is found.

- 3.110 A Theory of the Electrical Conductivity of Metals, Zyryanov, P. S.  
Zhur. Eksptl. i. Teoret. Fiz. 29, 193-200 (1955).

Methods developed in the theory of many-body systems are applied in the theory of the electrical conductivity of metals. The fluctuations associated with thermal motion are calculated by taking into account the collective Coulomb interaction between the electrons and the ions (the electron-ion plasma). These fluctuations cause scattering of the conduction electrons, and, thus, an electrical resistivity. Numerical values for this resistivity are calculated for Na, K, Rb, and Cs. The values (in  $10^{10}$  statohms/cm.) 26, 10, 6 and 4 respectively, are obtained which compare well with the corresponding experimental values 21, 13, 7, and 5. CA 50:16350

- 3.110 LIQUID METAL COOLANTS FOR NUCLEAR REACTORS  
R. W. Lockhart (KAPL)  
The Reactor Handbook, Vol. 2 Engineering, Chapter 2.1, p. 249-52  
1955

Covers Hg, K, Na, and NaK (2 references)

- 3.110 AECU-1199  
HEAT AND MOMENTUM TRANSFER IN TURBULENT FLOW OF MERCURY. Sheldon E. Isakoff and Thomas B. Drew. (nd). 25p.

It is found experimentally for mercury flowing vertically in a 1.5-in. tube in the Reynolds modulus range 36,700 to 373,000 that the ratio of the eddy diffusivity for heat to that for momentum varies directly with the 0.46 power of the Reynolds modulus and as a function of relative position in the cross section that is independent of Reynolds modulus. The velocity profiles for mercury agree essentially with those for other fluids. The temperature profiles are at variance with the predictions of Martinelli (Trans. Am. Soc. Mech. Engrs. 69, 947(1947)). The heat-transfer coefficients, although well approximated by the Martinelli-Lyon equations, increase more rapidly than those equations predict.

- 3.110 Density and Viscosity Measurements on Mercury and Highly Diluted Amalgamated Potassium and Cesium Between the Solidification Points and 30°. R. Suhrmann and E. O. Winter (Tech. Hochschule, Hannover, Ger.). Z. Naturforsch. 10a, 985-96 (1955).---

The temp. dependence of  $d$  and viscosity of the above substances was measured. The volumetric coeff. of expansion of amalgamated Cs  $\alpha_{Cs}$  is larger than  $\alpha_K$ . It increases, beginning with  $\alpha_{Hg}$ , proportionally to the concentration of the alkali metals. The same behavior was noted for the sp. vols. of the amalgams. The calcd. at. vols.  $V_K$  and  $V_{Cs}$  differ only by 10% and are independent of concn. They increase linearly with temp. The vol. contraction  $\delta$ , however, decreases with increasing temp. The temp. dependence of the viscosity  $\eta$  can be described with an accuracy of a few tenths per mill. by:  $\eta = \eta_0 \exp(q/RT)$  in which is a const.,  $q$  the energy for the exchange of places, which is for pure Hg 657.9 cal. For amalgamated K contg. 1.91 atoms of K per 1000 atoms amalgam  $q$  is 714.6 cal., and for an equally concd. amalgamated Cs  $q = 690.4$  cal. The K atoms are surrounded by a less densely packed cloud of Hg atoms of a larger vol. than the Cs atoms. The vols. of these clouds can be calcd. From their temp. dependence the energies  $E$  required to sep. 1 g. atom of Hg from the clouds were found to be:  $E_K = 278.9$  cal. and  $E_{Cs} = 359.3$  cal. CA 51-6255a

- 3.110 Diffusion in Molten Metals. IV. Diffusion in the Lead-Bismuth System, Niwa, Kichizo, et al, Univ. Hokkaido, Nippon Kinsoku Gakkaishi 19, 294-6 (1955); cf. C.A. 50, 126041

The diffusion coeffs. of Bi in the molten Pb-Bi system were measured under 2 different conditions. (1) At 450-600° with comparatively dil. solns., the use of the Gauss table of error integrals was permissible. (2) The influence of concn. on the diffusion coeff. was investigated at 500°. The results of method (1) were compiled according to the Arrhenius formula as follows:  $D = 0.00096 \exp(-4200/RT)$  sq. cm/sec. This confirmed that the diffusing substance in molten metals was the metal ions as described previously (loc. cit.). The value calcd. by the Stokes-Einstein equation (cf. Morgan and Kitchener (C.A. 48, 10407d)) in dil. solns. at 500° agreed only with the order of the exptl. value. The results of method (2) showed that the diffusion coeff. in the molten Pb-Bi system had a max. at an at. fraction of Bi of about 0.6. This agreed with thermodynamic properties of this soln., which had a strong neg. deviation from the Raoult's law.

CA 53:17853e

- 3.110 TID 3544  
ACTIVATION ENERGY VALUES FOR SPONTANEOUS DIFFUSION IN LIQUID METALS. K. A. Osipev. Doklady Akad. Nauk S.S.S.R. 121, 1019-20(1958)  
Aug. 21.

NSA 13:776

- 3.110 Diffusion in Molten Metals. V. Diffusion Coefficient of Antimony in Lead-Antimony System  
Niwa, Kichizo, et al., Univ. Hokkaido, Nippon Kinsoku Gakkaishi 19, 296-9(1955)

Diffusion coeff. of Sb in molten Pb were measured at 450-600°. Since the concn. of Sb was comparatively low, the diffusion coeffs. were estd. at consts. independent of concn. Thus,  $D = 0.0025 \exp (-6400/RT)$  was obtained. This showed that it was the cations of Sb that diffused in molten Pb-Sb soln. because the activation energy of diffusion was of the same order as in Pb-Sn and Pb-Bi solns. It was shown that metal cations diffused in molten alloys because the free vols. of metallic solns. were estd. to be larger than the values calcd. in accordance with the usual equil. theory. In other words, if the diffusing substances were assumed to be small particles, such as metallic ions, the theoretical value of the diffusion coeff. which was calcd. by using the atomistic theory of diffusion based on the intuitive free-vol. model in liquid, should be of the same order as that obtained experimentally.

CA 53:17853g

- 3.110 Cohesive Energies of Alkali Metals, Van Vleck, J. H.  
Proc. Intern. Conf. Theoret. Phys., Kyoto and Tokyo 1953, 640-8, discussion, 648-9 (Pub. 1954).

Methods of calculating cohesive energies are compared, and calculated and experimental values are given for the lattice constants, cohesive energy, and compressibility for the alkali metals. Values of the cohesive binding energies computed from quantum defects observed spectroscopically agree better with the experimental values than do those obtained from explicit wave functions. CA 50:15161

- 3.110 Precise Measurements of the Density of Mercury at 20°, I. Absolute Displacement Method  
A. H. Cook and N. W. B. Stone (Natl. Phys. Laboratory, Teddington). Phil. Trans. Roy. Soc. London, Ser. A, 250, 279-323 (1957).

The abs. measurement of the d. of Hg in units of length and mass is described. The result, 13.5458892 g./cc., is probably correct to 1 part in a million. The ds. of 4 samples of Hg were measured by finding the mass of Hg displaced by an accurately formed cube of known vol. that just sinks in Hg. CA52-8662a

- 3.110 AD 251781  
Lubrication Behavior of Liquid Metals, P. H. McDonald  
North Carolina St. College Raleigh. WADD TRE 9-764

The report describes the investigation of the lubricating behavior of liquid metals in 2 categories: hydrodynamic and boundary lubrication. The basic theory of hydrody. study is the Reynolds equation. This theory has been expanded after the manner of Christopherson to a new state of development. An experimental device has been designed and constructed for confirming theory as it relates to liquid metals. . . . . A macroscopic theory of boundary lattice region has been employed. This theory has been applied to a cylinder-flat combination, and the lubrication behavior has been seen to depend upon the state of contact stress for this configuration. Apparatus for this has been designed also.

- 3.110 NAA - SR - 878  
SODIUM GRAPHITE REACTOR QUARTERLY PROGRESS REPORT FOR JUNE-AUGUST 1953, G. M. Inman, ed. Jan. 20, 1954. Decl. Mar. 4, 1957. 118p.

In connection with the reactor engineering work, an investigation was carried out in order to optimize the cooling system and power plant conditions in the full-scale plant.

- 3.110 The Structure of Liquid Potassium by Lashko, O.S.  
Ukrain. Fiz. Zhur. 1, 403-6, Russian summary 406 (1956).

The structure of liquid K was investigated by aid of X-rays at 100 and 300°, with monochromatic Mo K radiation and with cylindrical specimens. The curves of the at. distribution were calculated according to the harmonic method, and the analysis of these curves showed that liquid Na and liquid K have indeed a similar structure. From the change of the position of the curve and of the area underneath the first max. of the curve the coordination number and the radius of the coordination sphere are determined. Thus at 100° the coordination number is 10, and the distance between adjacent atoms is roughly 4.7 Å. At 300° the radius of the coordination sphere becomes somewhat greater, whereas the coordination number drops to 9.

CA 51:8497

- 3.110 Calculation of the Change of Volume of Alkali Metals at the Melting Temperatures by Gertsriken, S. D.  
Voprosy Fiz. Metal. i Metalloved., Akad. Nauk Ukrain. S.S.R.  
Sbornik Nauch Rabot 1955, No. 6, 82-4

The volume V of alkali metals quickly increases when the metals melt. The phenomenon was studied theoretically and experimentally. Anomalies are explained.  $\Delta V/V$  is calculated (from literature data) also for the alkaline earth metals and for Zn, Cd, Ga, Sb, and Bi. (CA 51:9248)

- 3.110 Literature Survey on Properties of Sodium Vapor  
Ervin, Guy, Jr.  
Atomics International, Div. of North American  
Aviation, Inc. Canoga Park, Calif.  
NAA-SR-Memo 4417 September 25, 1959, 13 p.

A literature survey was conducted to assess the adequacy of published data on the properties of sodium vapor and to obtain information to be used as a basis for recommending experimental work on further measurement of these properties.

NSA 14:18892

- 3.110 NRL - Memo - 47  
Thermal Conductivity of Sodium-Potassium Alloy (77.7 wt. % Potassium),  
Curtis T. Ewing and Robert E. Seebold, Aug. 12, 1952. 7 p.

The thermal conductivity of Na-K alloy, 77.7 wt. % K, has been determined between 157 and 676°C. The conductivity increases from 0.2393 watts/cm-°C at 157°C to a maximum of 0.2618 at 445°C and then decreases to 0.2563 at 676°C. A graphic correlation of these results with those of two other previously reported alloys (48.3 and 56.5% K) is presented.

- 3.110 L. M. Roberts  
Radar Research Establishment, Malvern, Eng.  
The Atomic Heats of Lithium, Sodium and Potassium Between 1.5 and 20°K.,  
Proc. Phys. Soc. (London) 70B, 744-52 (1957)

The at. heats are measured with the view of determining the effective mass of the conduction electrons. For Li below 4°K the effective mass is 2.32 times that of the free-electron mass. Values of the at. heats are tabulated. Internal energies, entropies, and free energies are calcd.

CA 52:12478

- 3.110 AD 256611  
PHYSICAL PROPERTY CHARTS FOR SOME REACTOR FUELS, COOLANTS AND  
MICELLANEOUS MATERIALS  
Oak Ridge National Lab.  
Anon. (Fourth Edition), ORNL, O. R. Tennes. CF-54-6-188 Del. 15 p  
(June 21, 1954. Decl. with deletions Feb. 20, 1957)

Charts of physical properties of some reactor fuels, coolants, and miscellaneous materials have been prepared. Densities, volume expansion coefficients, heat capacities, thermal conductivities, viscosities, electrical resistivities, surface tensions, and melting temperatures are tabulated.

- 3.110 KAPL - M - LFE - 7  
Estimated Critical Constants, Extrapolated Vapor Pressure, and  
Equation of State of Sodium. Leo F. Epstein. Sept. 20, 1951.  
14 p.

Critical constants, vapor pressure, and equation of state of Na were extrapolated from low-temperature data and evaluated for high-temperature use.

- 3.110 NP-1108  
FRICTIONAL PRESSURE DROP FOR SODIUM-POTASSIUM ALLOY: TECHNICAL REPORT 1.  
Robert E. Lee. Sept. 1, 1949. Decl. Mar. 30, 1955. 21p. Contract  
N9onr-85801.

Tests were made measuring pressure drop of eutectic Na-K through a straight 1/2-in., seamless type 304 pipe. Plots are presented of the friction factor vs. Reynolds number curves as calculated independently using an orifice meter and an electromagnetic meter for flow measurements. Reasonable agreement was obtained between presently reported values calculated from the orifice meter and those previously. These curves are at variance with the values presently obtained from the electromagnetic flowmeter which give a friction factor vs. Reynolds no. curve agreeing closely with those recommended by Moody. Curves are given showing the variation of friction factor with Reynolds no. of 3,000 to 176,000. Since there appears to be more reason to validate the electromagnetic flowmeter values, good agreement is obtained with the curves recommended by Moody, so that ordinary methods of calculating pressure drop should give values sufficiently accurate for design purposes.

- 3.110 Connection Between Thermal Expansion and Potential Energy in  
Solids and Liquids, Borelius, G. (Roy. Inst. Technol. Stockholm)  
Arkiv Fysik 11, 217-27 (1946) (In English)

Previous work led to the relation  $(\Delta U / \Delta V) = (3/2) \alpha$ , where U is the increase in potential energy due to increased thermal fluctuations,  $\Delta V$  the change in volume and  $\alpha$  is the pressure parameter in  $(\Delta p + \alpha)(\Delta V + \beta) = \alpha\beta$  for pressure-volume changes of one mole of substance. Here, more tests are made of the relation by comparing it with experiments data for Cu, Ag, Au, Al, Pb, Na, K, Zn, and Hg in a wide range of temperatures. 33 references. CA 51:5498

- 
- 3.111 ENGINEERING PROPERTIES OF POTASSIUM  
Quarterly Report 8, July 1 - Sept 30, 1962 (NP-12305)  
A. W. Lemmon, Jr., BMI, Oct 30, 1962. 21p.

Measurements of the viscosity, vapor pressure, and heat capacity of K have been concluded. In addition, data for the thermal conductivity and electrical resistivity have been obtained at temperatures up to about 800°C.

NSA 17:3484

- 3.111 NP-11969  
ENGINEERING PROPERTIES OF POTASSIUM  
A. W. Lemmon, J. (BMI)  
7th Quarterly Report, April-June 30, 1962

Results of measurements of viscosity, vapor pressure, and specific heat of liquid K are given. Data from SS containers and Nb-1Zr are somewhat different. Brief discussions are given of equipment for measuring specific heat and PVT properties of potassium vapor.

NSA 16:27629

3.111 BNL-756

VAPOR PRESSURE OF ALKALI METALS III Rb, Cs AND NaK UP TO 100 psi

C. F. Bonilla, D. L. Sawhney, and M. M. Makansi

Columbia Univ., Second Annual High Temperature Liquid Metal Heat Transfer Meeting, Brookhaven National Lab, May 17, 1962

Vapor pressure data is presented for NaK (30.6 w/o Na), and for Rb and Cs up to 100 psi. The method of balancing the alkali metal vapor pressure with an externally controlled argon pressure was employed. The results for NaK were fitted to the equation log

$$P_{(\text{Atmos.})} = 4.12607 - \frac{4,397.99}{T (\text{°K})}$$

The NaK composition used had good agreement with values calculated from Raoult's Law.

3.111 BNL-756

ENGINEERING PROPERTIES OF POTASSIUM

Joseph F. Walling, B.M.I.

Second Annual High Temperature Liquid Metal Heat Transfer Meeting, Brookhaven National Lab., May 17, 1962

Current status on the research program on thermodynamic and physical properties of vapor and liquid phases of potassium. The data available was presented, including vapor pressures, liquid viscosity and heat contents at temperatures to 2100°F. The purity of the potassium is discussed, and the initial data represents properties of K containing 50 ppm oxygen or less.

3.111 The Saturation Vapor Pressure of Metals. II

Waldschmidt, E.

Metall 10, 1126-33 (1956).

The boiling point, melting point, heat of vaporization, and temperature at which a vapor pressure of  $10^{-3}$  mm. of Hg is obtained are tabulated for Cu, Ag, Au, Li, Na, K, Rb, Cs, Zn, Cd, Hg, Be, Mg, Ca, Sr, Ba, Al, Ga, In, Tl, Si, Ge, Sn, Pb, Ti, Zr, V, Nb, Ta, Sb, Bi, Cr, Mo, W, U, Fe, Co, Ni, Mn, Ru, Rh, Pd, Os, Ir, and Pt. Values of melting point and boiling point are not related systematically. Critical data for the same metals are also tabulated. If unimolecularity is assumed for the vapor at the critical points, the line of demarcation for the critical state runs through the values for He, F, and Ta; this indicates that critical pressures above 4000 atms. and critical temperatures higher than double the boiling point (in abs. temp.) can occur for no substance. However, much higher values are observed in the literature. For a pair of pressure/temperature values the following conditions must be fulfilled:

$$(\log P_{\text{crit.}})/T_{\text{crit.}} < (L_s/T_s f4.574) M_s - 0.1. \text{ On the basis of this}$$

relation the pairs of values that belong together at the critical state can be decided easily. More data are needed to reconcile the great variation in the experimental results thus far obtained. CA 51:5490

3.111 KAPL-M-LFE-7, Knolls Atomic Power Lab., Schenectady, N. Y.

Estimated Critical Constants, Extrapolated Vapor Pressure,

and Equation of State of Sodium, Epstein, Leo F., Sept. 20, 1951.

14 p. Contract W-31-109-Eng-52.

Critical constants, vapor pressure, and equation of state of Na were extrapolated from low-temperature data and evaluated for high-temperature use. NSA 10:10865

- 3.111 IS-273, A Condenser for the Vacuum Distillation of Metals,  
Burnet, G., Buchanan, W., (February 1961)

A condenser suitable for use in the distillation of metals was designed. The temperature of the condensing surface was established by controlling the pressure over boiling NaK-78 contained within the condenser. Performance was evaluated in test units in which pure bismuth was distilled as the test metal.

- 3.111 TID-2502 (Del.)  
ON THE REMOVAL OF  $\text{Na}_2\text{O}$  FROM Na BY DISTILLATION. Leo Brewer and John L. Margrave. p.233-4 of NUCLEAR SCIENCE AND TECHNOLOGY. (EXTRACTS FROM REACTOR SCIENCE AND TECHNOLOGY. VOL. 1, ISSUES 1 TO 3, APRIL-DECEMBER 1951. 2p. UCRL-1241(Rev.)  
\$41.40(ph), \$11.10(mf) OTS.TID 3544, NSA 12:17329

- 3.111 Experimental Determination of Potassium Vapor Pressure in the 550 to 1,280°C Temperature Range, Grachev, N. S., Kirilov, P. L., tech. trans. uv. F-66 of Inzhenerno-Fizicheskij Zhurnal 3:62-65, TAB 61:4:1 AD No. 260009.

An attempt was made to verify published data from experiments by Makansi (Jovan. Phys. Chem. 60, 128, 1956), and to broaden the previously investigated temperature interval. The potassium melting point was found to agree with other published data, but experiments yielded values for sodium and potassium vapor pressure than did those of Malsansi.

- 3.111 Technical Progress Report  
Sundheim, Benson R.  
New York, Univ. N. Y.  
NYO-7443 1 May 1957, 46 p.  
Contract AT(30-1)-1837

The activity of the components of alloys of Na and K are being determined as a function of composition. In the temperature range 200-300 C the vapor pressure of each component is being determined by measuring the optical absorption of the vapor at appropriate wave lengths. In the temperature range below 200 C an investigation is being made of a potentiometric method using glass membranes.

NSA 13:15949

- 3.111 AERE-M/R-1898. Gt. Brit. Atomic Energy Research Establishment, Harwell, Berks, England. THE MEASUREMENT OF VAPOUR PRESSURES BY A MODIFIED DEW-POINT METHOD WITH PARTICULAR REFERENCE TO THE SYSTEM MERCURY-MAGNESIUM. B. R. T. Frost and J. T. Maskrey. 1956. 23 p.

A number of thermodynamic functions of the components of a binary alloy system can be derived from the measurement of the vapor pressure of the more volatile component. Three different methods of measurement of vapor pressure were examined before the dew-point method was selected as giving the most accurate results and being the simplest to operate. The dew point was detected by the reaction of a photoelectric cell to a beam of light passing through a glass chamber containing the metal vapor. The apparatus was used to determine the vapor pressure of Hg over Hg-Mg alloys and over ternary Hg-Mg-Pb alloys. Thermodynamic activities and partial molar functions were calculated from the vapor pressure data. (auth)

- 3.111 Vapor Pressure of Sodium. Progress Report.  
M. M. Makansi, C. H. Muendel, and W. A. Selke. Dec. 1, 1953.  
6 p. Contract AT(30-1)-1101. NYO-3101  
J. Phys. Chem. 59, 40-2 (1955).

Experimental data on the vapor pressure of Na in the range of one to five atm. pressure have been obtained. The results are closely fitted by the equation of Rodebush and Walters,  $\log P = 7.5510 - 5400/T$ , where P is in millimeters of Hg and T is in degrees Kelvin. The experimental range is being extended. (For preceding period see NYO-3100.)



- 3.111 CF-56-4-31  
PROCEDURE FOR THE DETERMINATION OF OXYGEN IN SODIUM AND NaK BY  
THE DISTILLATION METHOD. J. C. White, Apr. 5, 1956. 11p.

The working procedure for the determination of O in Na and NaK by the distillation method is given. The apparatus, which is based on that developed by the Argonne National Laboratory, can be connected to either the direct sampling of static systems and makes possible the direct sampling of alkali at operating temperatures. Na and NaK have been sampled with this device at temperatures as high as 1400°F. The alkali metal is transferred, under pressure, to the sampler where a fixed volume of the metal is retained in a removable hemispherical cup. The metal is then distilled from the oxide at a temperature of 800°F and at a pressure of <5 microns of Hg. After the sampler has cooled, the cup is removed from the sampler and the oxide, which remains as a residue in the cup, is dissolved in water. The resulting solution of alkali metal hydroxide is then titrated to a methyl orange indicator end point with a standard solution of HCl. The concentration of O in the alkali metal is calculated on the basis of the equivalents of acid consumed in the titration, and the weight of the alkali metal, retained during sampling, in the cup.

- 3.112 THE SURFACE TENSION OF LIQUID METALS AS A FUNCTION OF  
TEMPERATURE. S. N. Zadumkin and P. P. Pugachevich  
 (Kabardino-Balkarskii State Univ., USSR and Kurnakov Inst. of  
 General and Inorganic Chemistry, Academy of Sciences, USSR).  
 Doklady Akad. Nauk SSSR, 146. 1363-6 (Oct. 21, 1962).  
 (In Russian)

On the basis of a static electron theory of the surface tension of a liquid metal, an expression was derived for the value of  $d\sigma/dT$  for a number of metals. The anharmonicity of the ion oscillations and the Fermi distribution function for an electron gas at  $T \neq 0$  were taken into account. The final expression is as follows:

$$\frac{d\sigma}{dT} = - \left\{ \left( \frac{0.044 \sigma}{T_2} \right) + \left( \frac{0.328}{V_a} \right) \left( \frac{V_a}{Z} \right)^{0.167} \left[ 1 + 0.832 \left( \frac{T}{T_s} \right) + 0.82 \times 10^{-4} \left( \frac{Z}{V_a} \right)^{0.333} V_a T \right] \right\}$$

Here  $T_s$  is the melting temperature, and  $V_a$  is the atomic volume. The value of  $d\sigma/dT$  was calculated from this formula for the following liquid metals: Li, Na, K, Rb, Cs, Cu, Ag, Au, Be, Mg, Ca, Sr, Ba, Zn, Cd, Hg, Al, Ga, In, Tl, Sn, Pb, Sb, Bi, Cr, Co, Ni, Rh, and Pd. The calculated values of  $d\sigma/dT$  are in satisfactory agreement with the experimental values for the non-transition metals (TTT). NSA 17:6708

- 3.112 A SUMMARY OF LITERATURE ON RELATION BETWEEN WETTING AND BOILING  
MERCURY HEAT TRANSFER  
 L. T. Clark, Aerojet-General Nucleonics, San Ramon, California,  
 November 1962. Report No. AN-766

A survey of the literature on the wetting properties of mercury and mercury amalgams is presented. The survey includes wetting, surface tension, and boiling studies. Interfacial phenomena are discussed as they are applicable to the mercury wetting problem. It was concluded that wetting is requisite for high heat fluxes in boiling, since non-wetting results in premature transition to film boiling and subsequent low heat transfer. Wetting may be induced by the addition of Na, K, and Mg. On the basis of this survey, it is concluded that wetting, as applied to high boiling fluxes, is of importance on a microscopic as well as a macroscopic scale. This survey is a preliminary study to pool boiling experiments for the SNAP-8 project for the National Aeronautics and Space Administration.

- 3.112 GAMMA RAYS IN DETECTION OF SURFACE TENSION AND MARGIN  
ANGLE AT HIGH TEMPERATURES. D. M. Ziv and B. I. Shestakov.  
Zhur. Priklad. Khim. 32, 1767-70 (1959) Aug. (In Russian)

The method can be used for determining the surface tension and angle of wetting at high temperatures and in opaque media. Commercially produced  $\text{Eu}^{154}$  and  $\text{Ir}^{192}$  are the most suitable sources. NSA 14:1684

- 3.112 SURFACE TENSIONS OF LIQUID ALLOYS OF BINARY METAL SYSTEMS WITH  
A MAXIMUM ON THE LIQUIDUS CURVES  
V. N. Yeremeko, V. I. Nizhendo, N. I. Levy, B. B. Boga-tyrenko  
(Metalloceram. and Spec. Alloys Inst., Akad. Sci., Ukr. S.S.R.)  
from Ukr. Khim. Zh. 28(4), 500 (1962)

- 3.112 SURFACE TENSIONS OF LIQUID METALS  
V. N. Yeremeko (Metalloceram. and Spec. Alloys Inst., Akad. Sci.,  
Ukr. S.S.R.) from Ukr. Khim. Zh. 28(4), 427 1962.

- 3.112 ER-5214  
MERCURY WETTING AND NON-WETTING CONDENSING RESEARCH  
Progress Report No. 3, July-December 1962, Contract NAS 3-2159  
R. G. Gido and A. Koestal, Rankine Power System Dept., TAPCO

This investigation consists of both an analytical and an experimental phase. The experimentation consists of local pressure drop measurements for condensing mercury in horizontal straight and tapered steel tubes. Both wetting and non-wetting conditions are explored. The analysis consists of the formulation of a dropwise condensing fluid mechanic model for correlating the data obtained from the non-wetting forced convection condensation tests. Also included is a hydromatic stability analysis of liquid films for application to wetting condensing and its multitude of possible flow patterns. This analysis is required to match the proper flow regime with its pressure drop correlation. The test data are compared with the Lockhart-Martinelli correlation to indicate agreement and note short comings. The state of the art of two-phase fluid mechanics is reviewed to give the reader a proper perspective of the work being done and the work that has been done. Non-wetting pressure drop data are tabulated herein with only preliminary attempts of correlation indicated. The final report will include the wetting data currently being obtained as well as the comprehensive results of correlation being compiled. (57 Ref.) (AGN Lib. 3-1241)

- 3.112 ENGINEERING PROPERTIES OF POTASSIUM  
Quarterly Report 8, July 1 - Sept 30, 1962 (NP-12305)  
A. W. Lemmon, Jr., BMI, Oct 30, 1962, 21 p.

Measurements of the viscosity, vapor pressure, and heat capacity of K have been concluded. In addition, data for the thermal conductivity and electrical resistivity have been obtained at temperatures up to about 800°C.

NSA 17:3484

- 3.112 Liquid Metals: Part V, The Role of  $\text{O}_2$  Films in the Wetting of  
Fe, Co, and Ni by Liquid Na and by Solutions of Ba and Ca in Liquid  
Na, by C. C. Addison, et al., J. Chemical Society 2699-705, July  
1962.

Discusses wetting at different temperatures apparently resulting from Na reaction in removing oxides. Additions of small amounts of Ca (> 0.07%) or Ba to Na(1) influences wetting rates profoundly.

NSA 16:25782

3.112 INFLUENCE OF MICRORELIEF ON THE SPREADING OF A LIQUID METAL ON A SOLID METALLIC SURFACE

Yu V. Goryunov, N. V. Pertsov, B. D. Summ, and E. D. Shchukin  
(Moscow State Univ.) Dokl. Akad. Nauk  
SSSR, 146: 638-41 (Sept. 21, 1962) (In Russian)

The spreading of adsorption-active liquid metals and alloys on solid metallic surfaces is an important problem in view of the lowering of the strength of the solid by the adsorbed material. Up to now, only surface diffusion, i.e., the migration of monomolecular layers was considered. However, the characteristics of the solid surface must also be taken into account. The problem was studied by observing the spreading of Hg on an oxide-free Zn surface. On a smooth surface, the Hg forms a  $70^\circ$  drop, spreading slowly according to the diffusion law:  $4 \sim t^{0.5}$ . On the other hand, spreading on a previously etched Zn surface presented a different picture; it followed the  $t^{0.3}$  law. Close consideration of the phenomenon showed that wetting, rather than two-dimensional migration is responsible for this phenomenon. No drop was formed on the solid surface; the effect of gravity could be noted, and the process was temperature-independent. It is not considered impossible that an ideally smooth surface cannot be wetted by a thin layer of liquid metal because the surface migration of the atoms lowers the surface energy of the solid in the area in front of the liquid phase, or, the presence of microrelief is required for wetting.

NSA 17:3503

3.112 NP-11969, Eng. Prop of K, 7th Quarterly, Apr 1-Jun 30, 1962, A. W. Lemmon Jr. BMI.

Results of measurements of viscosity, vapor pressure and specific heat of liquid K are given. Data from SS containers and Nb-1Zr are somewhat different. Brief discussions are given of equipment for measuring specific heat and PVT prop. of K.

NSA 16:27629

3.112 SURFACE TENSIONS OF LIQUID ALLOYS OF BINARY METAL SYSTEMS WITH A MAXIMUM ON THE LIQUIDUS CURVES. V. N. Yeremeko, V. I. Nizhenko, N. I. Levy, B. B. Boga-tyrenko (metalloceram. and Spec. Alloys Inst., Akad. Aci., Ukr. S.S.R.) from Ukr. Khim. Zb. 28 (4), 500 (1962)

3.112 SURFACE TENSIONS OF LIQUID METALS. V. N. Yeremenko (Metalloceram. and Spec. Alloys Inst. Akad Sci., Ukr. S.S.R.). from Ukr. Khim. Zh. 28(4), 427 1962.

3.112 "Calculation of Metal Surface Tensions: Ionic Salt and Monatomic Methods for Liquid Metals," S. W. Mayer, A.I., J. Chem. Phy. 35:1513-14, Oct. 61. (also CA 56:8033h)

It was found that surface tensions of molten metals can be calculated by using 1 of 2 models for metal. The ionic salt method was applied to alkali metals, etc.; others by monatomic. Surface tensions are given for K, Mg, Pb, Bi, Sb, Zn, Cd, Hg, Ag, Au, Al, Ga, Tl, and Fe.

NSA 16:1772

3.112 SURFACE PROPERTIES OF LIQUID SODIUM AND SODIUM-POTASSIUM ALLOYS IN CONTACT WITH METAL OXIDE SURFACES  
D. H. Bradhurst and A. S. Buchanan  
(Univ. of Melbourne) Australian J. Chem., 14: 397-408 (Aug. 1961)

Dissolved oxygen was shown to be surface active in liquid Na from measurements of surface tension and of contact angle of the liquid on various oxide surfaces. When sufficient oxygen was present wetting of  $UO_2$  by liquid Na was brought about at temperatures above approximately  $300^\circ C$ . Observations on the wetting of several solid oxides by Na gave some support to the hypothesis that wetting was more effective on these oxides with larger cations. NaK showed nonwetting contact angles when relatively free of oxygen but wetting occurred when the oxygen content of the liquid was increased.

NSA 15:32565

3.112 Certain Problems Related to the Viscosity of Fused Metals  
NASA TT F-88 AD 273-563

This monograph examines the theory of the torsional oscillation method for measuring the viscosity of liquids, and experimental technical problems associated with the use of this method, presents the results obtained during the measurement of the viscosity of fused metals and alloys, and gives a theoretical interpretation of certain problems concerned with the nature of the liquid state (structure of liquid, mechanism of the viscous flow, kinetics of crystallization, the effect of insoluble impurities on the viscosity, etc.).

This monograph includes original studies conducted by the author and his associates.

This book is of interest to scientific workers, such as physicists and engineers, engaged in a study of the problem of the liquid state.

3.112 The Temperature Dependence of the Viscosity of Liquid Metals  
S. W. Strauss (NRL) Oct. 23, 1961  
Nuclear Science and Engineering - Vol. 12, No. 3, March 1962,  
p. 436

Calculated and experimental viscosity data is plotted for Liquid Metals, and the graph includes Hg, K, and Na. (61 references are listed) (NSA 16:12147)

3.112 AN EMPIRICAL SURFACE TENSION TEMPERATURE RELATIONSHIP FOR LIQUID METALS  
S. W. Strauss, (USN Res Lab., Wash. D.C.) J. Nucl. Energy  
pt A & B 15, 28-9 (1961)

An equation was developed for relating the surface tension (values from literature) to the m.p. and critical temperatures for liquid metals (K, Na, Bi, Pb, In, Sn, Ce, Al, Ag, Au, Cu, Fe) for temperature range plotted. The difference between experimental and calculated surface tensions were <11%.

CA 57:14451

3.112 "Viscosity Measurements, XIV. Most Probable Values of Viscosity of Molten Sn, Pb, Bi and K," J. Budde et al, Z. Physik-Chem.,  
Lupzig 218:100-7 (1961) cf CA 55-25333i.

The most probable values of viscosities of molten Sn, Pb, Bi and K based on a critical study of literature values and on measurements are given.

CA 56:12326

3.112 GENERALIZATION OF EXPERIMENTAL DATA ON THE VISCOSITY AND THERMAL CONDUCTIVITY OF LIQUID METALS  
A. G. Usmanov (Translation)(FTD-TT-61-395)(p 121-341) (1961)

A generalization of the experimental data on heat transfer from liquid metals through walls and transfer processes in gas phases is discussed. Data are included concerning results obtained in a metallic group which includes Na and K.

NSA 17:282

3.112 MEASUREMENT OF THE SPEED OF ULTRASOUND IN MOLTEN ALKALI METALS  
Yu. S. Trelin, I. N. Vasil'ev, and V. V. Roshchvplcin. Atomnaya  
Energ. 9: 410-11 (Nov. 1960) (In Russian)

The pulse interferometer was used in measuring the ultrasonic speed in sodium and eutectic NaK at 700°C . . . It is also shown that ultrasonics can be efficiently used for testing construction material wetting by alkali metals.

NSA 15:10947

- 3.112 ON THE VALUE OF THE SURFACE ENERGY OF METALS AT THE CRYSTAL-MELT INTERFACE  
S. N. Zadumkin (Kabardino-Balkarsk State Univ.)  
Doklady Akad. Nauk. S.S.S.R. 130, 810-11 (1960)(In Russian)

A simple method is suggested for evaluating the surface energy at a polycrystal-melt surface. Results of  $\sigma_{12}$  calculations for body-centered cubic metals and experimental data on surface tension of liquid metals at their melting points are tabulated. The table indicates the interphase tension of metals at a polycrystal-melt interface as 8 to 15% of the surface tension at the melting point.

NSA 14:15078

- 3.112 ER-4103  
THE SNAP II POWER CONVERSION SYSTEM TOPICAL REPORT No. 7.  
MERCURY MATERIALS EVALUATION AND SELECTION  
(TID-11,307), J. J. Owens et al., October, 1960. 143p.  
Thompson-Ramo-Wooldridge, Inc., Cleveland, Ohio.

This report presents the results of a two-year material compatibility study and discusses the corrosion mechanisms involved in a system in which mercury is the working fluid. Includes 35 references and 11 bibliographies. (AGN Lib. 2-5632)

NSA 15:21096

- 3.112 ON THE VISCOSITY OF LIQUID METALS  
(O Vyazkosti Zhidkikh Metallov) A. M. Korol'Kov.  
Translated from Izvest Akad. Nauk, S.S.R. Otdel. Tekh.  
Nauk, Met i Toplivo. No. 5. 123-6(1959) 7p. (AEC-tr-4202)

Data on the viscosity of several metals and relations between the magnitude of their kinetic viscosity and other physical properties are presented. It is concluded that atomic volume and the entropy value can be used in objective viscosity evaluation of metals.

NSA 15:644

- 3.112 THE SURFACE TENSIONS OF LIQUID METALS AT THEIR MELTING POINTS  
S. W. Strauss (NRL, Nuclear Sci. and Eng. 8, 362,3, 1960) Oct.

An attempt to correlate surface tensions of liquid metals with other properties. The results were plotted as  $\log \gamma$  (surface tension) vs  $\log S$  (energy of vaporization per unit volume).

NSA 15:1886

- 3.112 HEAT TRANSFER DURING TRANSITION FLOW OF LIQUID METALS IN PIPES  
V. M. Deryugin and O. S. Fedynskii (Kozhezhanovskii Inst. of Power Engineering, Moscow). Inzhener. - Fiz. Zhur., Akad. Nauk Belorus. S.S.R. 2. No. 12, 3-10 (1959) Dec. (In Russian)

The "visual wetting" effect on heat transfer to liquid metals in a transition pipe flow is proved experimentally. The abrupt change in the heat transfer rate takes place at the hydrodynamic crises (Re<sub>2300</sub>) when the surface of the heat exchanger is wet, but does not take place when wetting is absent. (More on abstract.)

NSA 14:6416

- 3.112 Wetting of Refractory Oxide by Liquid Metals  
American Rocket Society Journal, Vol. 30, No. 9  
pp. 887 (September, 1960)

- 3.112 Wetting by Liquid Metals (AERE), J. W. Taylor, p. 398-416 in Progress in Nuclear Energy, Series V. Metallurgy and Fuels, Vol 2.

The wetting of solid metals and ceramics by liquid metals and alloys is of importance. Under ideal conditions, this wetting is controlled by the three interfacial tensions; (1) liquid-vapor, (2) liquid-solid, (3) solid-vapor, and the dependence of these on temperature and composition is outlined.

NSA 13:19354

- 3.112 "Moistening of Solid Surfaces of Certain Refractory Compositions With Liquid Metals," V. N. Eremenko E. Yu. V. Naidich, Bynl, Inst. Metallokeram i Spets Splavov. Akad. Nauk Ukr SSR 1959 No. 4 38-51.

A study was made of the wetting of solid oxides and borides with L. M. A relation was found between wetting of solid oxides and their physio-chemical properties. Oxides with high concentrations of free electrons, i.e., with a high elect. conduct. are wetted better with liquid metals. The elect. conduct. increases with decrease in heat of form. of oxides. The wettability of borides with melted Cu increases with increase in At. No. of corresponding transitional metal forming the boride; i.e., with a decrease in metal-B bond. An analysis of the literature data indicates that, in wetting of carbides, by metals, the decisive role is played by s-d (orbital) interaction and that only transition metals have a good wetting effect on carbides. Abstract from same author given previously.

CA 56:15169g

- 3.112 Wetting of Solid Metals by Liquid Metals  
Jordan, D. O. and Lane, J. E., Univ. Adelaide, Proc. Australian At. Energy Symposium 1958, 197-200

The theory of the wetting of solid metals by liquid metals is discussed and related to exptl. results. The effect of oxides, other metals, org. substances, and fluxes is described.

CA 53:16871h

- 3.112 Wetting Hard Surfaces of High Melting Compounds by Liquid Metals  
Yu. V. Nardich and V. N. Eremenko. Vaprosy Poroshkavoi Met. Prochnosti Insteredlov, Okak Nauk Ukr. SSR 6:56-64 (1958) (In Russian)

The wetting of oxides increased with the increase of electro conductivity. The wetting of carbides is determined by s-d orbital interaction. The wetting of borides by Cu (e) was studied at 1100 to 1400°C and correlated with other properties.

NSA 15:13414

- 3.112 Zmochuvannya Ridkymy Metalamy Poverkhen' Tuhoplavkykh Spoluk  
Wetting the Surface of High-Melting Alloys with Liquid Metals  
Eremenko, Valentyn Nykyforovych and Yuryy, Vladymyrovych Naydych  
Kiev. Vyd-vo AN Ukrayins'koyi RSR, 1958, 59p.

Problems of wetting high-melting alloys with molten metal, a process used in the manufacture of heat-resistant materials, are discussed. Results of experimental and theoretical investigations of the wetting process are presented and general thermodynamic principles are described. The book is intended for engineers and scientific personnel working in the physical chemistry of molten metals.

NSA 14:574

- 3.112 Mitra, S. S.  
University of Michigan, Ann Arbor  
Viscosity and Density of Liquid Metals  
Physica 24, 155-6(1958)

Many liquid metals obey the equations  $\eta = (A + B/T + CT)^3$  and  $(\eta/\rho)^{1/3} = a + b/T$  over a wide range of temperature T. Here  $\eta$  is the viscosity, the density, and A, B, C, a, and b are constants. Their application to Ca, Mg, Sn, and In is shown. (CA 52:14268)

- 3.112 JPRS-5006, Akademiya Nauk Ukr S.S.R. Institute Metallokeramika i Spetsial'nykh Splavov, Kiev, The Wetting of Refractory Compounds With Liquid Metals. Valentin N. Eremenko, Yu. V. Naidich 1958, 112p. (translation) OTS.

The general laws of wetting are presented. Data on the surface energies of L.M. at various temperatures are reviewed. Data in wettability (surface energies, wetting intensity, and external wetting angles) of various refractory metallic and non-metallic surfaces by liquid metals are reviewed. A connection between the properties of oxides and their low wettability was investigated . . . The results (of tests) confirmed the hypothesis that wetting of an oxide increases with an increase of the number of current carriers. The nature of the forces which act on the surface of boundary between the metal and the oxide and which produce the energy of association was investigated. Data on wetting of carbides and boride systems by liquid metals are reviewed.

NSA 14:22038

- 3.112 The Wetting of Solids by Liquid Metals by B.R.T. Frost (Atomic Energy Research Establishment, Harwell, England) Atomics 8, 387-90(1957) Oct.

The fundamentals of wetting are reviewed, and methods of measuring the wetting of metals by liquid Na, Bi, and Pb are discussed. Reactor problems concerned with wetting properties are summarized. These are concerned with corrosion, slurries, or suspensions, and thermal and electrical conductivity.

NSA 12:1410

- 3.112 X-Ray Investigation of the Structure of Liquid Metals of Similar Viscosities by Golik, A. Z. and D. M. Karlikov (State Univ., Kiev). Dopovidi Akad. Nauk Ukr. R.S.R. 1957, No. 3, 234-7 (Russian summary)

On the basis of earlier investigations of the viscosities and densities of amalgams those were selected which showed similar viscosities, such as Hg with 13.9 atom % Cd or 8.7 at. % Zn, and Hg with 18 at. % Cd or 12 at. % Zn, and they were investigated by aid of X-ray scattering in order to find out if there exists a connection between the viscosity coefficient and the structures of such liquids. All these solutions were molecularly miscible, and whenever 2 (Zn or Cd) solutions show similar viscosities, the intensity curves and the radial distribution functions of the X-ray scattering are similar. This now means that such liquids of similar viscosities have similar structures and show approximately the same order.

- 3.112 Belashchenko, D. K. (I. V. Stalin Steel Inst., Moscow) Viscous and Electric Properties of Liquid Binary Alloys and Their Connection with the Structure of the Liquid Zhur. Fiz. Khim. 31, 2269-76 (1957).

The kinematic viscosities of Cd-Sb, Pb-Tl, Bi-Tl, Sb-Sn, and Cd-Cu systems were determined in an apparatus based on the dampening of rotation vibrations of a cylindrical crucible with the liquid suspended on an elastic filament, by measuring the angle of twist in the magnetic field and the elec. cond. of the alloys. Both detns. could be made in one-test. (1) Sn-Sb alloys with 0.27, 2, 36.4, 43.3, 55.5 and 66.3 at. % Sb were studied at 900°; (2) Cd-Sb with 18-100 wt. % Cd at 450-650°; (3) Bi-Tl with 21-100% Tl at 350-650°; (4) Pb-Tl with 20-80 at. % Tl; (5) Fe-Na with 0-100 at. % Fe at 1550-1600°; (6) Cd-Cu with 11.3-55.7 at. % Cu at 550-650°. The viscosity and elec. cond. hysteresis were observed in 2, 3 and 4, but not in 1 and 6, which was correlated with the super cooling of the first group of alloys, but not of the second. The development of anomalies was more pronounced with greater deviation of alloys from ideal solutions (in the experimental order Pb-Tl → Sb-Sn → Fe-Ni → Bi-Tl → Cd-Sb → Cd-Cu. CA 52-8000

- 3.112 Calculation of the Viscosity of Molten Metals, by Anton Hrbek. Z. Metallk. 48, 603-5 (1957)

A more accurate equation is derived for ascertaining activation energies and an improved formula given for computing viscosities of molten metals. For Na the activation energy of self-diffusion was experimentally established (cf. C.A. 50, 2229h). This value is in good agreement with the one obtained when using the new formula. 35 references. CA 52:4437g

- 3.112 A. N. Solovlyev.  
Thermodynamical Similarity and the Viscosity of Fused Metals  
Atomnaya Energiya 3, 550-2 (1957)

An attempt was made to find a relationship between the thermodynamic and physical properties of a number of elements. The viscosity of fused Na, K, Li, Ru, Cs, Sn, Hg, Sb, Bi, and Ga was plotted against temperature. The curves fell into two groups, one for the alkali metals and the other for the rest of the metals. The hypothesis is made that the physical properties of similar metals could be deduced if the physical properties of one were accurately known.

NSA 12:10637

- 3.112 The Surface Tensions of Liquid-Metal Solutions  
Raylor, J. W. (AERE, Harwell, Berks, England).  
Acta Met. 4, 460-8 (1956). Sept.

Two analytical methods are presented for the calculation of the surface tensions of binary liquid-alloy mixtures. Calculated surface tension-composition relationships are compared with the corresponding experimental values for ten binary systems. For six simple eutectic systems the agreement is good. Three systems, showing intermediate phase formation in the solid state, exhibited considerable discrepancies between the calculated and experimental relationships. It is suggested that in these systems the surface has not the simple monolayer structure assumed in the analysis. In one system of peritectic form, the agreement was intermediate between the above two extremes. It was not found possible to invert the analysis to calculate activity - composition relationships from surface tension data, although this is theoretically possible. (NSA 10:11852)

- 3.112 BNL - 2620  
Heat Transfer Rates to Cross-Flowing Mercury in a Staggered Tube Bank. R. J. Hoe, D. Dropkin, and O. E. Dwyer. 1956. 34p.  
Submitted for publication in Transactions of the ASME

An experimental heat transfer program has been underway for some time at the Brookhaven National Laboratory, the general purpose of which is to obtain and correlate heat transfer coefficients for liquid metals flowing outside of tube banks. This paper covers one phase of the program, i.e., the measurement of heat transfer coefficients for mercury flowing normal to a staggered tube bank. The factors studied were (a) linear velocity, (b) tube location in the bank, (c) circumferential variation of the local coefficient for a single tube, (d) type of contact, i.e., "wetting" vs. "non-wetting" and (e) pressure drop. The local heat transfer coefficient varies smoothly from a maximum at the forward stagnation point to a minimum at the rear stagnation point in the Reynolds number range 15,000-80,000, the magnitude of the variation corresponding to a factor of 4-5. The average heat transfer coefficient for a tube in the interior of the bank varies as the 0.52 power of the velocity for non-wetted tubes and 0.66 for wetted tubes. For tubes located in the interior of the bank, wetted tubes give heat transfer coefficients considerably greater than those for unwetted tubes, e.g., at a Reynolds number of  $5 \times 10^4$  they are 35% greater. For a tube located in the front row, the difference was found to be much greater, the corresponding figure being 65%. The lower coefficients obtained in the front row of the tube bank compared to those in the interior, for the non-wetted tubes, is in general agreement with results obtained with ordinary fluids. Tubes located at the side walls give coefficients about 20% below those for tubes located in the interior of the tube bank.

- 3.112 Pool-Boiling Heat Transfer With Mercury. C. F. Bonilla, J. S. Busch, A. Stalder, N. S. Shaikhmahmud, and A. Ramachandran. p324-41 of Reactor Heat Transfer Conference of 1956 Held at New York, November 1-2, 1956. John E. Viscardi, comp. November 1957. 635p. (TID-7529(Pt. 1)(Bks. 1 & 2))

Hg was boiled on a horizontal low carbon steel plate at absolute pressures from 4 mm to 45 lb/in., liquid depths of 2 to 10 cm, heat velocities of 4,000 to 200,000 BTU/hr-ft<sup>2</sup>, and with and without wetting-agent additions. The nature of the boiling and the necessary temperature differential were observed. 13 references. Also in liquid metals technology. Part 1 of Chemical Engineering Progress Symposium Series (available in AGN-LIB C.1 3-689). No. 20-Vol 53:1957.



- 3.112 Heat Transfer Rates to Cross-Flowing Mercury in a Staggered Tube Bank - II. C. L. Rickard, O. E. Dwyer, and D. Dropkin. p.297-315 of Reactor Heat Transfer Conference of 1956 Held at New York, November 1-2, 1956. John E. Viscardi, comp. November 1957. 635p. (TID-7529 (Pt. 1)(Bks 1 & 2)

As part of a continuing liquid metal heat transfer program at the Brookhaven National Laboratory, both local and tube-average heat transfer coefficients have been obtained for the flow of Hg normal to a staggered tube bank. The bank consisted of sixty 1/2-in. tubes, six wide and ten deep, arranged in an equilateral triangular array. The present paper presents results showing the effects of flow rate. Prandtl number, wetting, gas entrainment, and tube location on the tube-average coefficients. The angular variation of the local coefficient has not been considered here, owing to the fact that the values have not been completely calculated from the original data. The Hg results are compared with a few results obtained with water in the same equipment. The heat transfer runs cover the Reynolds number range of 20,000 to 200,000, whereas the water runs over the range 8,000 to 20,000. Pressure drop results for both water and Hg flow through the tube bank are also reported. The Hg coefficients for tubes in the interior of the tube bank are well represented by the equation.  $Nu = 4.03 + 0.228 (Pe)^{0.67}$ . 7 references.

- 3.112 Viscosity of Molten Metals by Brunello, Giovanni (Univ. Sao Paulo). Bol. dept. quim. escola politec. (Univ. Sao Paulo) No. 3, 19-38 (1956).

A review with 64 references.

CA 51:9447

- 3.112 Viscosity of Metallic Melts  
Yao, Tung-Ping (Tech. Hochschule, Aachen, Ger.)  
Giesserei Tech. - Wiss. Beih. Giessereiw. u. Metallk. 1956, 837-51.

The literature relating to the theory of structure of liquid metals and of viscosity is reviewed, and the 3 methods for viscosity determination (capillary, rotation, vibration) are compared. The ball-vibration method is demonstrated with water-glycerol mixtures and compared with data obtained with Al, Sn, Pb, Ca, Zn, Sb, and Bi... Proportionality between viscosity and heat of melting, melting point, and surface tension in some metals suggests that strong bonding forces are expressed in high viscosity values. CA 51:4085

- 3.112 TID 3544  
ENERGY OF ACTIVATION OF THE VISCOSITY OF MOLTEN ALLOYS. (AKTIVACNE ENERGIE VAZKOSTI ROZTAVENYCH SLITIN). Antonin Hrbek. Translated for Naval Research Lab., Washington, D. C. from Hutnicke listy 11, 715-21(1956). 12p. (NRL-Trans-659). NSA 12:16401

- 3.112 TID-7526 (Pt. 1)  
Ames Lab., Ames, Iowa, Metallurgy Information Meeting,  
Ames Laboratory, Iowa State College, May 2, 3, and 4, 1956. 234p.

The topics included are: Nondestructive testing of EBWR fuel plates; Wetting temperatures of fuel element components with Na and NaK; strengthening of Be for H High temperature use with BeO and Be<sub>2</sub>C dispersions; mechanical metallurgy of Zircaloy-3B; mechanical properties and corrosion behavior of Zircaloy-3B; constitution of U and the Pt metals; production of Th-Bi dispersions; preparation of radio-analysis of Kr and Xe and its use in diffusion experiments with Ag, preferred orientation in extruded Th rod; morphology of Zircaloy-2; microstructural appearance and identification of hydrides in Zr and Zircaloy-2-H<sub>2</sub> alloys; inspection of small diameter tubing by Eddy current methods; application of immersed ultrasonic technique for the inspection of small diameter tubes; corrosion and mass transfer by Li at high temperatures; and siliconizing of metals in liquid NaK. NSA 11:4464

- 3.112 Activation Energy of the Viscosity of Molten Alloys  
Hrbek, Antonin  
Hutnicke listy 12, 715-21 (1956).

Viscosity activation-energy values are enumerated for the molten binary alloys Ag-Au, Au-Cu, Ag-Cu, Bi-Pb, Bi-Sn, Pb-Sn, K-Na, Mg-Pb, Mg-Sn, Cu-Sb, and Cu-Sn. The calculated activation energies confirm the validity of the equation  $Q = Cf.R. T_m$  for molten alloys and compositions. The existence of structure in molten alloys is confirmed and the influence of the chem. compositions and admixtures on the viscosity of alloys is explained. The equation for the calculation of the binding energy of molten alloys is derived. It is possible to calculate viscosities at arbitrary temperatures from the compositions and physical constants. CA 51:5668

- 3.112 The Activation Energy of Viscosity of Metallic Melts  
Hrbek, Anton  
Zeitschrift fur Metalkunde, Vol. 48, No. 3, pp. 134-137 (March 1957).

The author reviews mathematical expressions for the temperature dependence of viscosity. Using published data, largely those of Gebhardt and co-workers, he plots energy of activation of viscosity for eight alloy systems and classifies these plots into three groups: (1) One group exemplified by Ag-Au in which the activation energy follows the rule of mixtures; (2) a second group including Cu-Sn, Mg-Pb, and Cu-Sb, in which there are reasonably sharp maxima corresponding to intermetallic compounds; and (3) a third group containing Bi-Sn, Pb-Bi, Ag-Cu, and Au-Cu in which there is a broad maximum corresponding to what the author terms "imaginary chemical compounds", or "conglomerates of polyionic molecules" which he suggests might be related to eutectics.

- 3.112 The Viscosity and Structure of Liquid Solutions of Zinc, Cadmium, Tin, Bismuth, and Lead in Mercury.  
Golik, A. Z. and N. A. Rindich  
Ukrain. Fiz. Zhur. 1, 170-81 (Russian summary, 181-2) (1956)

The viscosity coefficient was measured by a method proposed earlier and was improved by protecting the amalgam against oxidation in the viscometer by application of dilute solutions of an acid. The densities were measured in a pycnometer. The densities decrease almost linearly with rising temperature. The curves of the viscosity as a function of temperatures between 300 and 900°K of all these solutions lie between the curves of the components. The following concentrations (in wt. %) result in identical viscosity curves: 8.3 Cd or 3.7 Zn, 11.0 Cd or 4.3 Zn, 20.0 Cd or 8.0 Zn. The activation energies for viscous flow were a linear function of the concentration. Only the viscosity curve of Pb in Hg shows a distinct min.; owing to their different structures the viscosity curves for Sn, Pb, and Bi amalgams are more complicated than the ones for Zn and Cd. The results for the last two alloys can be interpreted by considering the potential-energy curves for Zn and Cd in Hg. The lower the min. in these curves, the higher the binding energy, the higher the critical temperature of the metal under consideration, and the higher its viscosity. As the viscosity-temperature curve of the alloy lies between the ones for the components, the potential curves for Zn and Cd in Hg must lie between the ones of the components too, and the depth of the min. there (also of the bond energy, critical temperature, and viscosity) depends on the concentration of Zn or Cd, respectively. These data are evidence that there is a relation between the viscosity and the structure of the mol. field of liquids. 16 references

CA 50:15179

- 3.112 TID 3544  
Golik, A. Z.  
Molecular Structure and Viscosity of Liquid Metals and Alloys  
Nauk Zapiski Kiev. Inst. 14, No. 8, 159-69 (1956). (Translated from Referat Zhur. Fiz. No. 3, 1957. Abstract No. 6396). (NRL)  
NSA 12:12435

- 3.112 Solid Metal-Liquid Metal Interaction Studies. Part II. Contact Angle Relationships for Sodium on Solids  
Taylor, J. W. and Ford, S. D. United Kingdom Atomic Energy Authority, Res. Group Atomic Energy Research Establishment, Harwell, Berks, AERE-M/R-1729 Nov. 19, 1955 26 p.

Using a sessile drop technique, a study has been made of the contact angle behavior of liquid sodium on a variety of solid metals and ceramics in the temperature range 100 to 550 C. Sodium forms a contact angle of less than 90° on all the metals studied at temperatures in the range 300 to 400 C. The corresponding temperatures for the ceramics are a little higher. No dewetting of the materials occurs on cooling and this, in conjunction with the observed influence of absorbed gas on the solid surface, suggests that in the early stages the contact angle temperature relationship is not one of equilibrium. While tension is high as shown by an experimental value of 580 dynes/cm for the sodium-copper interface; the failure of sodium to attack metals intergranularly would support the view of a high interfacial tension. The low surface tension of sodium accounts for the ease of wetting. In structures, either metallic or ceramic, in which the bond strength is weak and or, stressed, complete disruption or failure of the solid can occur when the contact angle falls below 90°.

NSA 13:9684

- 3.112 Molecular Structure and the Viscosity of Liquid Metals and Alloys.  
A. Z. Golik. Nauk. Zapiski, Kiiv. Derzhav. Univ. im. T.G. Shevchenka 14, No. 8, Zbirnik Fiz. Fak. No. 7, 159-69 (1955).

A treatment of viscosity  $\eta$  of liquid metals is described that follows the theory of viscosity for org. liquids contg. different mol. species. The key to understanding the behavior is said to be the temp. dependence of  $\eta$ . The  $\eta$  of Hg, Cd, and Zn was measured with a flow viscometer. The  $\eta$  varied with temp. according to the relation  $\eta = \eta_0 \exp(\beta/RT)$ . The effect of Cd and Zn dissolved in Hg was studied. Equiv. effects were observed for 8.3% Cd and 3% Zn, 11% Cd and 4.3% Zn, and 20% Cd and 8% Zn. The viscosity of 52% Zn in Hg was equiv. to 100% Cd. The theoretical treatment is based on variations in the strength of nearest-neighbor attraction. Some incomplete data are given on Cu-Ag and Pb alloys.

CA 51:16030e

- 3.112 NP-5690  
Progress Report No. 28 for April and May 1955, J. W. Mausteller, ed. June 21, 1955. 70p. Contract NObs-65426.

Tests on the Mark B 3000-Kw steam generator were continued. Engineering studies are summarized on vent and line closures, cross flow exchanger, electromagnetic pumps, pressure gages, liquid metal leakage, alkali liquid metal surface wetting, corrosive effects and waste disposal of Na, and testing of Mark A and B bellows, valves, and apparatus for thermal shock measurements. The changes in the solubility of Na<sub>2</sub>O in liquid Na due to the addition of Na or K were investigated. Mass transfer inhibition was examined. The removal of radioactive Na by flushing was investigated. Loop tests and pipe-flushing tests were continued. The radiation hazards arising from leaks in the water cooling system of a reactor and the possible chemical reactions between water and molten metals were studied. (For preceding period see NP-5601.)

- 3.112 NP - 5811  
Wetting With Sodium. Technical Report No. 43. M. H. Wahl. (MSA) Nov. 8, 1955, 13p. Contract NObs-65426.

Certain pretreatments (aqua regia, NaOH, electropolish, and Na<sub>3</sub>PO<sub>4</sub>) have been shown to enhance wetting of stainless steel by molten Na at low temperatures. Wetting was neither speeded nor retarded by contact with cover gas (98%N<sub>2</sub>-2%O<sub>2</sub>).

- 3.112 NP - 5779  
Progress Report No. 30 for August and September 1955. W. J. Posey,  
ed. Oct. 11, 1955. 78p. Contract NObs-65426.

The results of tests on models of the Submarine Intermediate Reactor Mark B 3000-kw steam generators are reported. Data from steady state and cyclic operation have been obtained. The system has been shut down for cleaning, inspection, and repairs. Heat transfer with liquid metals flowing perpendicular to tube bundles is being studied, and some performance data are presented. An induction pump for liquid metals has been designed using the principle of the watt-hour meter. Tests are being performed to determine conditions influencing the low temperature wetting of surfaces with alkali liquid metals. The testing of valves and bellows for use in the SIR sodium system is described. Mockups have been constructed of the expansion tank and other components in the Mark B Na system. Tests are being performed on them to determine the effects of the use of impure N containing 2 vol.% O as a cover gas for the Na system. Methods of leak plugging are being studied for water to mercury leaks in the Mark A steam generating system. The removal of residual radioactive Na from a cooling system by means of Na flushes is being studied using  $\text{Au}^{198}$  as a tracer. The study of radiation hazards arising from leaks in a simulated contaminated water cooling system of a nuclear reactor is continuing. (For preceding period see NP-5739.)

- 3.113 NP - 5713  
Wetting Effects on Boiling Heat Transfer. Final Report for  
March 1, 1954 through May 31, 1955 on Project No. A-153. W. B.  
Harrison, Zelvin Levine, Frank A. Thomas, Jr., and LeRoy A. Woodward.  
66p. DA Project No. 599-01-004. Contract DA-01-009-ORD-368.

In order to study effects of wetting on heat transfer in the nucleate boiling regime, stearic acid was boiled in contact with different crystal planes of single crystals of Cu. In the region of low heat flux, where heat transfer is primarily non-boiling natural convection, the non-wetted crystal required higher value of temperature difference than the wetted crystal. This is consistent with the notion that non-wetting conditions represent increased thermal resistance. At high values of heat flux, though not in the vicinity of the critical temperature difference, the situation was reversed. This is consistent with the notion that it is easier to form bubbles with non-wetting conditions than it is with wetting conditions. The ranges of variables were: pressure, 17mm of mercury; boiling temperature  $465^{\circ}\text{F}$ ; heat flux, 3250 to 63,300 Btu/hr/ft<sup>2</sup>; heat transfer coefficient, 91 to 510 Btu/hr/ft<sup>2</sup>/ $^{\circ}\text{F}$ ; temperature difference, 38 to 132 $^{\circ}\text{F}$ . 23 figures, 129 references.

- 3.112 NP-5601  
Progress Report No. 27 for February and March 1955. J. W. Mausteller,  
ed. Apr. 22, 1955. 62p. Contract NObs-65426.

Tests on the Mark B 3000-Kw steam generator are described, including a circulating cold trap and plugging indicator, system cleaning, pump performance, NaK furnace tube failure, boiler water analysis, and heat transfer. Engineering studies are summarized on vent and drain line closures, NaK cross flow exchanger, development of EM pumps, pressure gages, wetting with alkali liquid metals, thermal shock, bellows testing, valve cleaning and testing, and thermal insulation tests in liquid Na. The depression of  $\text{Na}_2\text{O}$  solubility in Na by K is discussed. Further studies on inhibition of mass transfer of radioactive stainless steel constituents in Na are described. The removal of residual radioactive Na with Na flushes was studied. Further results on radioactive leak contamination and the reactions of molten Zr in water are reported.

- 3.112 Viscosity of Molten Metals  
 Shvidkovskii, E. G.  
 M. V. Lomonosov State Univ. Moscow  
 Gidrodinamika Rasplavlen, Metal., Akad. Nauk S.S.S.R.,  
 Inst. Masjinoved., Trudy 1-go Soveschchaniya 1955,  
 45-55 (Pub. 1958); cf. C.A. 48, 11275F.

The structure, the relation between the viscosity and the structure, and the role of viscosity in the flow, and the heat-exchange processes of molten metals are discussed. It was postulated that a liquid consisted of 2 groups of particles: an atom or aggregate of atoms vibrating about a center corresponding to the state of a statistically disordered crystn., lattice, and particles moving chaotically. Cluster formation in evapn., observed by Honing (C.A. 47, 9084b), suggests fragmentation of quasicrystals in the liquid state. Heat conductance in the liquid state is similar to that in the solid and gaseous states. The effect of impurities on supercooling, the equality of the ratios of the Reynold nos. to the viscosities of 2 liquids, and the heat transfer in straight tubes at laminal and turbulent flows are discussed.

I. Bencowitz

CA 53:12116f

- 3.112 Density and Viscosity Measurements on Mercury and Highly Diluted Amalgamated Potassium and Cesium Between the Solidification Points and 30°  
 Suhrmann, R. and E. O. Winter (Tech. Hochschule, Hannover, Ger.)  
 Z. Naturforsch. 10a, 985-96 (1955).

The temperature dependence of density and viscosity of the above substances was measured. The volumetric coefficient of expansion of amalgamated Cs,  $\alpha_{Cs}$  is larger than  $\alpha_K$ . It increases, beginning with  $\alpha_{Hg}$ , proportionally to the concentration of the alkali metals. The same behavior was noted for the sp. vols. of the amalgams. The calculated at. vols.  $V_K$  and  $V_{Cs}$  differ only by 10% and are independent of concentration. They increase linearly with temperature. The volume contraction  $\delta$ , however, decreases with increasing temperature. The temperature dependence of the viscosity  $\eta$  can be described with an accuracy of a few tenths per mill. by:  $\eta = \eta_0 \exp(q/RT)$  in which  $\eta_0$  is a constant.,  $q$  the energy for the exchange of places, which is for pure Hg 657.9 cal. For amalgamated K containing 1.91 atoms of K per 1000 atoms amalgam  $q$  is 714.6 cal., and for an equally concentrated amalgamated Cs  $q = 690.4$  cal. The K atoms are surrounded by a less densely packed cloud of Hg atoms of a larger volume than the Cs atoms. The vols. of these clouds can be calculated. From their temperature dependence the energies  $E$  required to separate 1 g. atom of Hg from the clouds were found to be:  $E_K = 278.9$  cal. and  $E_{Cs} = 359.3$  cal. CA 51:6255

- 3.112 Viscosity and Molecular Structure of Liquid Metals  
 Golik, A. Z.  
 Stroenie i Fiz. Sviostava Veshchestva v Zhidkom Sastoyanii  
 (kiev: Izdatel. Univ.) Shornik 1954, 83-5; Referat. Zhur.,  
 Khim. 1956. Abstr. No. 25031

Hg, Cd, and Zn, similar in their structure when liquid, were chosen to investigate the relation between the viscosity  $\eta$  and structure. The crit. temps. of Cd and Zn, 2529° and 2910°, resp., are detd. by the known relation of the crit. and boiling temps. of Hg. The curves  $\eta = f(t)$  for these metals appear higher when the crit. temp. of the substance is higher; similar phenomena are observed with liquid Li, Na, K, Pb, and Cs. The viscosity of the liquid alloys Cd in Hg and Zn in Hg was investigated. The curves  $\eta = f(t)$  lie between the curves of the components and are higher when the b.p. and, consequently, the crit. temps. are higher. The curves  $\eta = f(t)$  are identical for the following solns.: 20% Cd in Hg, and 8% Zn in Hg; 11% Cd in Hg, and 4.3% Zn in Hg; 8.3% in Cd in Hg and 3% Zn in Hg. The temp. effect on  $\eta$  is exponential. The facts cited show the relation between the viscosity and mol. structure in the liquid state, also the expediency of investigating groups of liquids of similar mol. packing and similar types of intermol bond. CA 52:3444a

3.112 AEC-TR-2497

An Experimental Investigation of the Surface Tension of Sodium Amalgams Pugachevich, P. P. and O. A. Timofeevicheva. Translated by F. L. Yaggee Doklady Akad. Nauk S.S.S.R. 94, 285-7 (1954).

Results are reported of the experimental investigation of the surface tension of sodium amalgam containing from  $8 \times 10^{-5}$  to 0.284 at. % of Na. The surface tension measurements were conducted at  $22^{\circ}\text{C}$  under high vacuum. Surface tension of Hg drops by 2 to 3 dynes/cm even at  $8 \times 10^{-5}$  at. % Na (1 gr Na per 10 tons of Hg). In contrast to previous works, no especially small value on the surface tension isotherm has been observed. It was concluded that the adsorption scheme in metallic solutions is much simpler than was previously suggested.

3.112 BNL - 270

Quarterly Progress Report October 1-December 31, 1953.  
(Unclassified Section). 66p.

Liquid Metal Heat Transfer. The purposes of this project are to obtain (a) average film coefficients for individual tubes and (b) the variation of the local film coefficient with angle for individual tubes, for cross-flow of Hg in a staggered-tube bank. Reproducibility of results from run to run was poorer than expected, particularly for tubes located at or near the front of the tube bank. It appears that two pertinent factors are: (a) improved "wetting" with passage of time and (b) variability of the flow pattern after each start-up. By imbedding nine thermocouples on each test tube to avoid the necessity of rotating it, and by using temperature recorders, data-taking has been speeded up and the results are more precise. Some typical coefficient profiles for a tube located in the central portion of the tube bank are shown. The local coefficient for a given Reynolds number varies gradually from a maximum at the forward stagnation point to a flat minimum at the rear stagnation point. Generally, the value of the coefficient at  $180^{\circ}$  is about half that at the front. The average coefficient, for the tube as whole, is shown as a function of Reynolds number. The straight line drawn through the data has a slope of approximately 0.5.

3.112 The Spreading of Liquid Metals on Solid Surfaces: Surface Chemistry of High-Energy Substances. A. Bondi (Chem. Rev., 1953, 52, (2), 417-458).

A review covering the following topics: thermodynamics of the spreading of liquids on surfaces, surface tension of liq. metals, surface tension of fused metal oxides and metallic sales, surface free energy of solid metals and metal oxides, interfacial free energy between high-energy substances, Metal/non-metal systems, wetting of solid surfaces by metals and alloys, wetting agents, spreading on and by non-metals. 70 ref. -- I.S.S.

3.112 Boiling and Condensing of Liquid Metals

C. F. Bonilla and B. Misra. April 25, 1953. 9p.  
Contract AT(30-1)-1042. (NYO-3152). Dep.; Ind. Dep.

Additional runs have been made on the condensing of Hg vapor at atmospheric pressure and 330,000 to 650,000 Btu/hr-ft<sup>2</sup> on carbon-steel, stainless steel, and Ni, under wetting, semiwetting, and nonwetting conditions. The highest heat-transfer coefficient observed under any conditions was 2345 Btu-hr-ft<sup>2</sup>-°F, for completely wetted Ni, which is less than 20% of the theoretical Nusselt value. Tests run in the presence of H and of N showed that traces of inert gas were not causing the decrease in coefficient. It is believed that the decrease is due to thermal contact resistance between the Hg and the condensing surface. This hypothesis is supported by earlier work on contact resistance.

- 3.112 Heat Transfer to Mercury in Turbulent Pipe Flow. H. A. Johnson, W. J. Clabaugh, and J. P. Hartnett, July 1953. 63p. Contract AT-11-1-gen-10, Project 5, Phase II. (AECU-2627). Trans. Am. Soc. Mech. Engrs. 76, 505-11(1954); Dep. (mc)

Experimental heat-transfer results are presented for turbulent flow of nonwetting Hg in a 3/4-in., 18-gauge mild-steel tube with constant heat flux. The identical test heat exchanger developed for the previously reported investigation of molten Pb-Bi eutectic was used. This present investigation also includes a series of short duration tests for possible effects due to (1) secondary flow. i.e. vertical upward vs. downward heated flow, (2) the use of A as an alternate for a He atmosphere, and (3) the addition of Mg-Ti amalgam as a wetting agent. Heat-transfer tests with H<sub>2</sub>O preceded and followed those for Hg to establish continuing reliable performance of the test exchanger and its instrumentation. The results are correlated for the Peclet modulus range from 200 to 10,000 and are 4 to 10% lower than the previously reported values for Pb-Bi and 25 to 40% lower than the Martinelli-Lyon momentum theory. No difference in heat-transfer performance was noted for upward vs. downward flow or for the use of A as a replacement for He. No visible evidence of wetting occurred on the addition of the Mg-Ti amalgam, and no effect was found in the heat transfer.

- 3.112 ORO - 121  
Effect of Wetting on Heat Transfer Characteristics of Liquid Metals. Progress Report. R. M. Boarts, Harold Chelemer, and Bernard Hoffman. Feb. 1, 1954. 11p. Contract AT(40-1)-1310.

Progress is reported on the determination of the effect of wetting on the heat transfer characteristics of Hg by the use of additive wetting agents and variation of the heat transfer material. An effort was made to reduce the detachment effect of a modified Hg flow system (ORO-93) by operating under vacuum and by eliminating splashing of Hg in the reservoirs. The former showed little change, but a marked decrease in the detachment effect resulted from the latter change, indicating they were caused by entrained gas. Investigations on a smaller scale showed that detachments like those above could be obtained by applying a vacuum to a glass vessel containing Hg which had been vigorously aerated. The density of aerated Hg was found to be as much as 12% less than that of nonaerated Hg. The design of an apparatus to be used in measuring the temperature distribution in a steel-Hg-steel system is presented.

- 3.112 ORO - 100  
Effect of Wetting on Heat Transfer Characteristics of Liquid Metals; Progress Report. R. M. Boarts, Harold Chelemer, and Bernard Hoffman. July 31, 1953. 7p. Contract AT-(40-1)-1310.

The apparatus previously used (cf. report ORO-93) in the heat transfer studies has been modified to allow Hg delivery to the test section from an overhead reservoir 20 ft above the test section. This arrangement was chosen in order to eliminate any possible air entry sources present in the original system which might have caused the detachment phenomenon observed when a glass tube was used as a test section. However, this change resulted in an even greater amount of detachment. A series of photographs of the detachments was taken under several flow conditions. Studies are to continue to determine the nature and origin of this phenomenon and its effect on heat transfer coefficients. An investigation of contact angles between Hg and solid metal surfaces has been completed resulting in the formulation of two distinct types of wetting. Continued studies concerning interface phenomena are planned with the measurement of interfacial resistivities between mercury and solid metals under mercury flow conditions.

3.112

BNL-337

LIQUID METAL HEAT TRANSFER. p. 30 of Quarterly Progress Report for January 1 - March 31, 1955. (Unclassified Section). 61 p.

The second phase of the program is now being undertaken for the purpose of extending the range and number of variables previously investigated and studying further the effect of "wetting." The experimental conditions which will be used are listed. The factors to be studied are: linear velocity; tube location; effect of angle on the local coefficients around the circumference of a given tube; type of contact, i.e., "wetting" vs. "nonwetting"; geometry; and Prandtl number. The experimental methods and equipment will be essentially the same as those used in the previous work.

3.112

ORO - 93

Effect of Wetting on Heat Transfer Characteristics of Liquid Metals (thesis). W. K. Stromquist, Mar. 1953. 182p.

The effect of wetting on heat-transfer characteristics of liquid metals has been investigated by the use of additive wetting agents in Hg to permit direct comparison of wetting and non-wetting heat-transfer data in the same apparatus. The heat transfer system was of the single-tube type, directly heated by electric current in the tube wall. Low-carbon steel tubes of 3/8, 1/2, and 3/4-in. diameter were used as test sections, and pure Hg and 0.02% Na amalgams were used for tests under non-wetting and wetting conditions, respectively. An extensive series of tests was conducted over a range of Prandtl modulus from 0.017 to 0.022, a range of Peclet modulus from 88 to 19,400, and a range of Reynolds modulus from 5150 to 900,000. Results indicate that there is no steady inherent property of a non-wetted liquid-metal system that causes low heat transfer coefficients as compared with a wetted system, and that the erratic heat transfer data sometimes observed in non-wetted systems are due to random local detachment of the liquid from the tube wall. Similar erratic behavior may occur in wetted systems with rough walls. The detachment, with its corresponding erratic heat-transfer behavior, can be prevented by maintenance of sufficient pressure within the fluid, or more generally, by maintenance of a sufficiently high value of the Euler modulus (ratio of static head to velocity head).

3.112

ORO - 89

Studies of Interfacial Effects Between Mercury and Steel. Joseph J. Droher. June 1952. 92p. Contract AT-(40-1)-1310.

This investigation was undertaken to determine the effect of wetting on the heat-transfer characteristics of Hg by the use of additive wetting agents and by study of characteristics of heat-transfer-surface materials. Determination was made of heat-transfer data over a wide range of flow rates under both wetting and non-wetting conditions and a study was made of the characteristics of various solid metals in contact with Hg by examination of contact angles and electrical resistivity at the surface. A survey of the literature was made and information pertinent to these problems was collected. An apparatus was designed and constructed to measure the interfacial electrical resistance between a liquid and a solid metal surface. 89 references.

3.112

ORO - 76

Effect of Wetting on Heat Transfer Characteristics of Liquid Metals; Quarterly Report for Period May 1 - July 31, 1952. R. M. Boarts, H. Chelemer, and W. K. Stromquist. July 31, 1952. 5p.

The purpose of this investigation is to determine the effect of wetting on the heat transfer characteristics of Hg, a typical liquid metal, by the use of additive wetting agents and variation of the heat-transfer-surface material. During this fifth quarter, the initial phase of the study of contact angles between Hg and steel under varying conditions has been completed (Kett's Thesis, June 1952) heat transfer data have been obtained under wetting and non-wetting conditions, and preliminary results of physical property measurements of pure Hg and dilute amalgams have been obtained. This work is summarized in report ORO-93.



- 3.112      ORO - 70  
Effect of Wetting on Heat Transfer Characteristics of Liquid  
Metals; Fourth Quarterly Report. R. M. Boarts and W. K. Stromquist.  
Apr. 30, 1952. 4p. Contract AT-(40-1)-1310.

The first phase of the study of electrical resistivity at Hg-solid metal interfaces has been completed, the measurement of contact angles of Hg against steel has been started, and the heat transfer system has been completed and placed in operation. In the study of electrical resistivity it was found that Cu always gave low interfacial resistivity, stainless steel always gave high resistivity, low carbon steel gave both high and low resistivities under apparently identical conditions, and that wetting was a sufficient but not a necessary condition for low interfacial electrical resistivity. No data are included.

- 3.112      ORO - 60  
Effect of Wetting on Heat Transfer Characteristics of Liquid Metals.  
Third Quarterly Report. W. K. Stromquist and R. M. Boarts. Jan. 31,  
1952. 6p. Contract AT-(40-1)-1310.

The purpose of this investigation is to determine the effect of wetting on the heat-transfer characteristics of mercury, a typical liquid metal, by the use of additive wetting agents and variation of the heat transfer surface material. Work during the first two quarters consisted of development and the start of construction of apparatus for the study of interface effects and determination of physical properties of mercury and diluted amalgams, and operation of a pilot-model heat transfer system. During the third quarter the interface studies have progressed rapidly and construction of the heat transfer system has been started. Preliminary measurements of electrical conductivity at mercury-solid metal interfaces indicate significant differences between wetting and non-wetting conditions with respect to conductivities at the interface. Tests have shown that newly created steel surfaces immersed in mercury are wetted without additive wetting agents. A device for measuring contact angles of mercury in controlled atmospheres at elevated temperatures has been built.

- 3.112      NP-4010  
HEAT TRANSFER TO MERCURY. D. L. R. Bailey, W. F. Cope and G. G. Watson.  
July 1952. 32p. Heat Div. Paper No. 13

The results of measurements of heat-transfer coefficients using a parallel-flow heat exchanger with Hg as the working fluid are reported. The measurements cover the whole range of turbulent flow from the critical up to a Reynolds number of about 100,000. The measured forced convection coefficients are compared with those calculated from existing empirical formulae (McAdams, Eagle and Ferguson) and with those calculated from the momentum-transfer and vorticity-transfer theories of turbulent flow and with such other measurements as are available. In all cases the agreement is poor; the reasons for this are discussed and it is concluded that the most probable reason is that, under the conditions of these measurements, the Hg did not wet the walls of the tube. Nevertheless the results should provide data from which a Hg heat exchanger could be designed to an accuracy of  $\pm 25\%$  for conditions under which no wetting takes place. If the Hg does wet the walls then the coefficient will be multiplied by a factor which is tentatively put at about three from a survey of all available information. This uncertainty emphasizes the urgent need for measurements under wetting conditions.

- 3.112     The Calculation of the Viscosity of Liquid Metals (with Special Reference to Lithium)  
Smith, E. S.  
Great Britain. Div. of Atomic Energy (Production)  
Risley, Lance, England  
January 1952, 11 p.  
RDB(R)/TN-1

Results indicate that the relationship between the viscosity and temperature for liquid metals is of a type similar to that suggested for liquids in general. The viscosity of lithium at its melting point was calculated to be 0.006 poises and the variation of viscosity of molten lithium with temperature was estimated. An equation for the summation of fluidities was found to give good results when applied to the calculations of the viscosity of K-Na alloys from the known viscosities of the compounds. There is apparently a connection between the viscosity of the liquid metal and its position in the Periodic Table.

NSA 13:12444

### 3.120     THERMAL PROPERTIES AND HEAT TRANSFER

- 3.120     A Statistical Analysis of Nucleate Pool - Boiling Data, G. A. Hughmark (Ethyl Corp., Baton Rouge La.) Intern. Journal Heat and Mass Transfer, 5:667-72, July 62 (In English)

Nucleate pool boiling experimental data were analyzed with a statistical technique to obtain an 8 variable equation for the heat flux . . . . An average absolute deviation of 40% was obtained between experimental and predicted heat flux for a range of materials from boiling H<sub>2</sub> to boiling Hg.

NSA 16:30564

- 3.120     Thermophysical Prop. of Molten Metals, Yer. P. Os'minun (all Union Correspondence Power Eng. Inst., Moscow) Inzhener. Fiz. Zhur. Akad. Nauk Belorus. SSR 5: No. 2 108-12 (Feb 63) In Russian

The relationship between temp. and heat conduction, temp. conduction heat capacity and surface tension of L. M. is studied. Dimensionless relationships are obtained for Sn, Bi, Hg, Na, K.

NSA 16:16741

- 3.120     NP-12330  
VIBRATIONAL SPECTRUM OF SODIUM. S. K. Joshi and M. P. Hemkar (Allahabad, India. Univ.) (p. 399-406) Madras Sympos., March 2, 1962

Conduction electrons produce difficulties in finding the correct atomic force constants for a calculation of lattice vibrational properties of metals. Various three-term approximations for Na have failed, and a five-year approximation following Houston's method gives an expression for the frequency distribution function. Constants used in calculations come from former works; and graphs display values of specific heat for Na at different temperatures, the lattice vibrational spectrum of Na, and Debye characteristics as a function of temperature. Better agreement is obtained for the Debye curve than was obtained in earlier research.

NSA 17:7132

- 3.120     AD277751 Kinetics of Condensation From the Vapor Phase  
Texaco Experiment Inc. W. G. Courtney, period ending 15 July 1962.

A theoretical and experimental investigation was made of the kinetics and mechanisms of condensation and particularly of homogeneous nucleation from the vapor phase . . . . (Reportedly one of the matls utilized was mercury for the tests.)

- 3.120 BNL-756  
SUMMARY OF SODIUM BOILING AND CONDENSING STUDIES  
R. C. Noyes, Atomics International, Second Annual High Temperature Liquid Metal Heat Transfer Meeting, Brookhaven National Lab., May 17, 1962
- Heat transfer coefficients for nucleate boiling and condensing were found to be very high (as expected). The burnout heat flux measurements have confirmed the dominant influence of hydrodynamic parameters, but have also shown an important influence of liquid transport properties. Experimental problems with equipment for pool boiling and with forced convection boiling techniques were described.
- 3.120 BNL-756  
ALKALI METALS BOILING AND CONDENSING INVESTIGATIONS  
R. D. Brooks, GE-FPLD, Cincinnati, Ohio, Second Annual High Temperature Liquid Metal Heat Transfer Meeting, Brookhaven National Lab., May 17, 1962

Forced convection boiling and condensation in single tubes was studied. Three convection experiments were in progress ranging from 50 to 300 KW at the test sections. This includes an L-605 alloy loop for temperatures up to 1850°F, and a Cb-1Zr loop for measurements up to 2200°F. Equipment characteristics and preliminary data are included.

- 3.120 BNL-756  
LIQUID METALS HEAT TRANSFER TEST PROGRAMS  
J. J. Killackey, AiResearch, Second Annual High Temperature Liquid Metal Heat Transfer Meeting, Brookhaven National Lab., May 17, 1962

Experimental boiling test of potassium up to 1480°F with forced swirling within heated tubes. Preliminary data on heat fluxes up to 320,000 BTU/hr ft<sup>2</sup> at 15% vapor quality was included.

LiH purification and liquid handling at 1400°F was described.

- 3.120 BNL-756  
FORCED-CONVECTION SATURATION BOILING OF POTASSIUM  
W. W. Hoffman and A. I. Krakoviak, ORNL, Second Annual High Temperature Liquid Metal Heat Transfer Meeting, Brookhaven National Lab., May 17, 1962

Equipment development for forced convection boiling program at ORNL. Heat transfer and boiling data presented for potassium at 1360 to 1430°F. Liquid metal purity maintained by gettering continuously through Ti sponge.

- 3.120 BNL-756  
ALKALI METAL PHYSICAL PROPERTIES PROGRAM AT P&W AIRCRAFT - CANEL  
R. E. Cleary and S. M. Kapelner  
Second Annual High Temperature Liquid Metal Heat Transfer Meeting, Brookhaven National Lab., May 17, 1962

Program review presented on the physical properties program on alkali metals and NaK in progress at CANEL. The data reported to date included electrical resistivity data (also in PWAC-349), and thermal conductivity up to 865°C. Effort was continued to extend the latter data to higher temperatures (1300°C for Li), and to continue other physical property measurements including viscosity, vapor pressure, vapor density, and wetting characteristics.

- 3.120 NRL 5344, AD 284340, NRL Wash., D.C., HIGH TEMPERATURE PROPERTIES OF SODIUM AND POTASSIUM by C. T. Erving, J. P. Stone, et al., 27 Aug. '62, Progress Report #7

An experimental program is underway to measure several thermophysical properties of Na, K and their vapors, at elevated temperatures. The status of each property test is discussed and preliminary values are reported for density of K(l) from 1564 to 2282°F and for equilibrium solubility of Nb and Zr in Na(l) from 1470° to 2507°F.

- 3.120 BNL-756  
GEOSCIENCE, LTD., PROGRESS REPORT ON HIGH TEMPERATURE LIQUID METAL  
 HEAT TRANSFER FOR THE AEC  
 H. F. Poppendiek and N. F. Greene  
 Second Annual High Temperature Liquid Metals Heat Transfer  
 Technology Meeting, May 17-18, 1962
- Report presents the results of several analytical and experimental programs sponsored by the AEC, as follows: 1) Review of Past Liquid Metal Heat and Momentum Transfer Research, 2) Analytical Two-Phase Flow, Heat Transfer, and Thermodynamic Studies, 3) Preliminary Hg Heat Transfer System Studies, and 4) Experimental Two-Phase Flow Momentum Transfer Studies, including helical flow compared with annular flow for two phase conditions.
- 3.120 BNL-756  
EDDY DIFFUSIVITY EFFECT IN LIQUID METAL HEAT TRANSFER  
 O. E. Dwyer, B.N.L.  
 Second Annual High Temperature Liquid Metals Heat Transfer  
 Technology Meeting, May 17-18, 1962
- A study of the analytical approach to heat transfer under turbulent flowing liquid metals in circular pipes and concentric annuli. The equations generated were found to check precisely with experimental heat transfer data where the values of eddy diffusivity for heat transfer, and the eddy diffusivity for momentum transfer could be determined. The latter values were found to vary substantially within the flow area of a pipe.
- 3.120 BNL-756  
HIGH TEMPERATURE BOILING MERCURY EXPERIMENT  
 C. J. Baroczy, Atomics International, Second Annual High Temperature  
 Liquid Metal Heat Transfer Technology Meeting, May 17 and 18, 1962.
- A description of experiment equipment and materials employed for Hg boiling and heat transfer work. The system was in design and ready for fabrication. Duplex tubes consisting of low carbon steels clad with Inconel X or with Haynes Alloy 25 were studied.
- 3.120 THERMOPHYSICAL PROP. OF MOLTEN METALS  
 Yu. P. Os'minion, Inzh.- Fiz. Zh. Akad.-Belorussk, SSR5. No. 2;  
 108-12 (1962)
- Dimensionless 2nd degree empirical eq. are obtained for certain thermophysical properties of some molten metals. For Sn, Bi and Hg, as a group, a single set of relations is found for heat condition thermal diffusivity and surface tensions as functions of temperature and m.p. A similar eq. is obtained for heat condition of Na and K as a group. Extrapolation with these eq. yield values for thermophysical quantities in extrapolation inaccessible temperature regions.
- 3.120 Heat and Momentum Transfer in Liquid Metals  
 Edgar H. Buyco (Purdue U. Lafayette Ind.) Univ. Microfilms  
 (Ann Arbor Mich) Order No. 61-6519 168 pp. Dissertation Abst.  
 22 2319-20 (1962).  
 CA 56:11391e
- 3.120 RUBIDIUM - CESIUM EVALUATION PROGRAM THERMODYNAMIC PROPERTY  
 MEASUREMENTS BNL-756  
 D. L. Cochran, Aerojet-General Nucleonics, San Ramon, California  
 Presented at the Second Annual Meeting on High-Temperature Liquid-  
 Metal Heat Transfer Technology held at BNL, May 17-18, 1962.
- This paper summarizes thermodynamic property measurements on Rb and Cs which have been made by AGN under contract to the U.S.A.E.C. Density of saturated liquid between the melting temperature and 1350°F and vapor pressure between 1000 and 1800°F are presented for both Rb and Cs. Additional work in process and planned is also described.

- 3.120 CORRELATION OF DISSOCIATION ENERGIES OF GASEOUS MOLECULES AND OF HEATS OF VAPORIZATION OF SOLIDS. PART I. HOMONUCLEAR DIATOMIC MOLECULES  
G. Verhaegen, et. al., (Universite Libre, Brussels) Trans. Faraday Soc., 58:1926-38 (Oct. 1962) Includes Hg. NSA 17:6095

- 3.120 AD-284340  
HIGH TEMPERATURE PROPERTIES OF SODIUM AND POTASSIUM, PROGRESS REPORT No. 7, APRIL 1 - JUNE 30, 1962  
Ewing, C. T., Stone, J. P., and others. (Naval Research Lab., Washington, D. C.) August 27, 1962. 6p., incl. tables. 4 refs. (NRL Report No. 5844)

An experimental program is underway to measure several thermophysical properties of sodium, potassium, and their vapors at elevated temperatures. The status of each property test is discussed, and preliminary values are reported for the density of liquid potassium from 1564° to 2282°F, and for the equilibrium solubility of columbium and zirconium in liquid sodium from 1470° to 2507°F. (Author)

- 3.120 AD-270-775, Calculation of the Thermodynamic Properties and the Construction of is - Diagrams for Alkali Metals, Shil'rayn, E. E. and Asinovsky, E. I. (Jan. 1962)

On the basis of data available on the thermodynamic properties of alkali metals and vapor phases, a method was developed for calculating their thermodynamic functions. An analysis is made of the effect of dimerization in the vapor of alkali metals and a method is shown for taking into account this effect when calculating the enthalpy, entropy, and pressure of saturated vapor. An is-diagram (enthalpy-entropy diagram) is shown for liquid metals.

NSA 16:9220

- 3.120 NP 11969, Eng. Prop of K, 7th Quarterly, Apr 1-Jun 30, 1962, A. W. Lemmon Jr. BMI.

Results of measurements of viscosity, vapor pressure and specific heat of liquid K are given. Data from SS containers and Nb-1Zr are somewhat different. Brief discussions are given of equipment for measuring specific heat and PVT prop. of K.

NSA 16:27629

- 3.120 AD282370 - Univ. of Michigan .  
Investigation of Liquid Metals Boiling Heat Transfer, Quarterly Progress Report #3 in Phase 2a by Richard Balzhiser, C. P. Colver et al, July 62, p. 133-34.

Abstract describes test program primarily with K and Na. At end he states " . . . studies with Hg are scheduled."

- 3.120 Average and Local Heat Transfer for Crossflow of Liquid Hg in a Tube Bank, C. L. Rickard (Cornell Univ., Ithaca, N. Y.)  
Dissertation Abs. 22:2742 (Feb 1962)

Local and heat transfer coefficients were obtained for the flow of mercury normal to a staggered bank of tube . . . Results are presented showing the effects of Reynolds No., Prandtl No. wetting of the tube surfaces by the Hg, gas entrained in the liquid metal flow . . . ; gas entrained in the liquid metal flow reduces heat transfer coefficients only under condition of non-wetting and wetting or non-wetting of the heat transfer surfaces has no effect on the coefficients in the absence of gas entrainment and surface fouling; friction factors measured for the flow of mercury through the tube bank under non-wetting conditions are in general agreement with those of ordinary fluids and wetting or non-wetting of the tubes surfaces in a tube bank has little or if any effect on the pressure loss . . . for heat and momentum. For practical calcn. of film coefficient of heat transfer, an interpolation formula is proposed.

NSA 16:22310

- 3.120 THE TEMPERATURE RANGE OF LIQUID METALS AND AN ESTIMATE OF THEIR CRITICAL CONSTANTS. A. V. Grosse, (Temple University, Phil. P.A.) J. Inorg. Nucl. Chem. 22, 23 (1961-1962)

- 3.120 IADC-5403  
CONVERSION OF  $C_V [T, V(T)]$  TO  $C_V [T, V(0^\circ K)]$  WITH APPLICATION TO Na AND Cu.  
 W. C. Overton, Jr. (Los Alamos Scientific Lab., N. Mex.)  
 J. Chem. Phys., 37:2975-85 (Dec. 15, 1962).

The thermodynamic quantity  $E(T) = \int_0^T (\partial C_V / \partial V)_T dV = C_V [T, V(T)] - C_V [T, V(0^\circ K)]$  may be evaluated in terms of the thermal expansion and the coefficients,  $\alpha_i$ 's, in the solid equation of state and their derivatives. Slater's procedure for  $E(T)$  is extended herein to the case in which the  $\alpha_i$ 's are arbitrary function of temperature and pressure. This  $E(T)$  is then transformed to a second equivalent form in terms of the bulk modulus and its temperature and pressure derivatives. It is seen that  $C_V [T, V(0)]$  may be determined entirely from experimental data. The lattice specific heat  $C_L [T, V(0)] = C_V [T, V(0)] - T \gamma_e [V(0)]$ , the physically correct way of calculating  $C_L$  from electronic specific heat measured at low temperatures, is determined for Na and Cu. The  $C_L [T, V(0)]$  of Na is compared with the Bornvon Karman theoretical  $C_{theoret}$  calculated by C. B. Clark, this comparison indicating an anharmonic  $C_L$  of the form  $C_{theoret} (1 + AT + BT^n)$ , ( $5 < n < 6$ ), where A is only one-sixth that calculated by Leibfried and Ludwig for  $C_p [T, V(T)]$ . Comparison of  $C_L [T, V(0)]$  of copper with theoretical specific heat calculated by the author shows quantitative agreement (within 0.2% from 50 to 300°K) thus indicating the adequacy of the central force model with nearest and next - nearest - neighbor forces used. NSA 17:8063

- 3.120 ASD TR61-594 (AD 270481) Literature Survey on Liquid Metal Boiling,  
 Final Report, Phase I, R. E. Balzheser et. al., Univ. of Michigan.  
 Dec. 1961

A survey is made of information pertaining to current status of liquid Metal Technique... Particular attention is called to the solid-liquid interfacial energy and its importance in limiting H.T. across interface. Contains summary of physical properties of liquid metals.

NSA 16:25522

- 3.120 HIGH TEMPERATURE PROPERTIES OF SODIUM  
 C. T. Ewing, J. P. Stone, J. R. Spann, T. A. Kovacina, and R. Miller, NRL Memo. Report 1236, Oct. 1961

The thermodynamics and transport properties of Na to 2500°F.

- 3.120 Jung, E. "Measurement of the Thermal Contact Resistance Between Liquid Sodium and Stainless Steel," Nukleonik 3, 250-6 (Nov. 1961) (in German).

A very accurate method for the measurement of the thermal contact resistance between stationary liquid sodium and stainless steel is given. Twenty-four contact surfaces were wired in series. It could be proved with certainty that the contact resistance of this pairing is smaller than  $10^{-6} \text{ m}^2 \text{ hgrd/K col.}$  The method is principally applicable to other liquid/solid combinations.

- 3.120 GENERALIZATION OF EXPERIMENTAL DATA ON THE VISCOSITY AND THERMAL CONDUCTIVITY OF LIQUID METALS  
 A. G. Usmanov (Translation) (FTD-TT-61-395) (p 121-341) 1961

A generalization of the experimental data on heat transfer from liquid metals through walls and transfer processes in gas phases is discussed. Data are included concerning results obtained in a metallic group which includes Na and K.

NSA 17:282

- 3.120                   "Turbulent Heat Trans in Liq Metal - Fully Developed Pipe Flow with Constant Wall Temp." N. Z Azer & B. T. Chao. Intern J. Of Heat Mass Transfer 377-83 (1961)

Nu and temp profile for low Pr fluids of const prop. flowing in a smooth pipe with const. wall temp. were eval. Use is made of the theoretical expression for ratio of eddy diffusivities.

CA 56:290e

- 3.120                   Analyt. Study of Heat Trans. Rates For Parallel Flow of Liq. Metals thru Tube Bundles II, A. J. Friedland and C. F. Bonilla (BNL) AIChE Journ. 7, 107-12 (1961)

Describes a theoretical analysis of heat trans to liq metals in parallel flow through tube bundle.

CA 56:9908i

- 3.120                   LIQUID METALS WORK SUMMARY  
R. W. Carpenter, Aerojet-General Nucleonics  
Notes on Conference on Properties of Alkali Metals at BMI, April 1961

Covers 1) static corrosion capsule tests, 2) proposed loop program, and 3) thermodynamic measurements.

- 3.120                   SUMMARY OF NRL SODIUM PROGRAM  
J. P. Stone, Naval Research Laboratory, Wash. D. C.  
Notes on Conference on Properties of Alkali Metals at BMI, April 1961.

Thermodynamic properties, (materials of containment include Cb-12r).

- 3.120                   WORK ON LIQUID METALS  
C. F. Bonilla, Columbia University, N. Y.  
Notes on Conference on Properties of Alkali Metals at BMI, April 1961

Thermodynamic properties of K.

- 3.120                   NUCLEAR REACTOR HEAT TRANSFER TECHNOLOGY  
M. E. Lapides, General Electric Co., Phila., "Progress in Nuclear Energy," Ser. IV 4:29-50 (1961)

Contains analytical and experimental data on heat transfer for liquid metals. Effects considered include, among other things, surface roughness.

NSA 16:12831

- 3.120                   HEAT TRANSFER TO MERCURY IN THE TRANSITION FLOW RANGE  
V. N. Zmerkov and B. P. Ustimenko, Tr. Inst. Energ. Akad. Nauk. Kaz. SSR 3:147-55 (1961)

Heat transfer applications involving liquid metals (Hg, Na, K, etc.) are becoming more and more numerous; but experimental data are scattered and often contradictory. The apparatus is described. Some fifty calibration runs covered flow in Reynolds number range 1400 to 21,000. Subsequently, about eighty runs were made, using technical grade Hg as the heat transfer medium. The data are plotted. The results were compared with heat transfer data for H<sub>2</sub>O, gasoline and oil in the transition flow velocity region. These heat exchanger calibration techniques might prove useful in many investigations where actual determination of the exchanger will temperature is either difficult or not feasible.

CA 56:12689b

- 3.120                   AD 257-693, Liquid Metal Research in the Inst. of Nuclear Research In 1956-58, 14 June 1961, Transl.

Results of research work in liquid metals are analyzed. These results are analyzed. These results are focused mainly on tests of pumping and circulating of liquid metals in cooling systems on studies of heat transfer and on measurements of flow and viscosity of liquid metals.

3.120 AD 282159, Nucleation in Condensation From the Vapor Upon a Substrate, J. P. Hirth, Ohio State Univ. Research Found.

A recent theory of Lothe & Pound indicates that appreciable entropies of formation of embryos markedly affect homogeneous nucleation from the vapor phase. Similar constraints are considered here for nucleation on substrates, using a statistical development of a nucleation rate expression. It is shown that nucleation may be very dependent on surface contributions to the entropy of formation of a nucleus.

3.120 "The Thermal Condition of Na and Li," I. I. Rudnev et. al. At. Energy, USSR 11:230-2 (1961)

Equation for calculating the thermal-condition coefficient ( $\alpha$ ) for molten Na (in the range of 350-876°)....are  $\alpha_{Na} = 0.721 - 0.0174 \times 10^{-2}T$ , where T is °C. An error of equation is  $\pm 2.5\%$  for Na.  
CA 56:8032a

3.120 "Heat Transfer for Turbulent flow of a Liquid Metal in a Tube." V. I. Subbotin et al. AT Energ. (USSR) 11 133-9 (1961).

The radial temp. distributed in a 30-mm Stainless Steel tube was detd. for alkali metals at Re of 16,200 and 24,700 and at heat fluxes of 40,000 and 39,500 kcal/sq m-hr. and for heavy metals at Re of 24,200 and 204,000 and at heat fluxes of 17,800 and 41,000 kcal/m<sup>2</sup>-hr. The wall temp. required to calculate the heat trans. coefficient was detd. by extrapolating the temperature profile of the liquid metal to the wall. The data fit the formula of Lyon (CA45 3205h) over a wide range of Pe of 100 to 12,000:  $Nu = 7 + 0.025 Pe^{0.8}$ . However, if the contact thermal resist. due to the oxide film on the heavy liq. metals is plotted as a function of Re. Chemical analysis shows that the content of oxide near the wall was about a factor of 10 greater than the content of oxide in the main stream of the heavy liquid metal.

CA 56:11390h

3.120 APPLICATION OF THE EWING EQUATION FOR CALCULATING THERMAL CONDUCTIVITY FROM ELECTRICAL CONDUCTIVITY (KAPL-2146)  
A. E. Powers (Knolls Atomic Power Lab., Schenectady, N. Y.)  
Apr. 7, 1961. Contract W-31-109-Eng-52. 21p.

The usefulness of the Ewing equation for calculating the thermal conductivity of reactor metals and alloys from electrical resistance, specific heat, density, and atomic weight was investigated. The alloys investigated were Zircaloy-2, HSZA, Nb-5.5 wt% V, Inconel, 18-8 stainless steel, and eutectic NaK. The Ewing equation was found to give calculated values with a degree of confidence similar to that of actual measured values.

NSA 15:25218

3.120 AN EXPERIMENTAL EQUATION OF STATE FOR SODIUM  
R. I. Beecroft and C. A. Sewnson (Ames Lab., Ames, Iowa)  
Phy. and Chem. Solids, 18:329-344 (March 1961).

An equation was obtained for pressures to 20,000 atm and from 20°K to the mp. Various experimental details are given of an apparatus with which it is possible to obtain pressure-volume data which are reliable to  $\pm 0.002$  in  $\Delta V/V_0$  over this range of temperature and pressure. The equation of state can be represented to within the above accuracy by an expression which is derived from the assumption that the isothermal compressibility is linear with volume and has no explicit temperature dependence. A discussion is given of the effect of these assumptions on the validity of calculations of the variation with volume of the temperature dependent contribution to the thermodynamic functions. Grueneisen constants as obtained from various definitions are calculated as functions of temperature and volume, and the validity of the Mie-Grueneisen equation of state as it applies to Na appears open to question below room temperature. Recent high pressure ultrasonic experiments on Na are interpreted as being in agreement with this conclusion.

NSA 15:19378



3.120 LIQUID-METALS PHYSICAL PROPERTIES PROGRAM  
R. Cleary, Pratt & Whitney Aircraft  
Notes on Conference on Properties of Alkali Metals at BMI, April 1961  
Solubility of gases in liquid metals, and thermodynamic properties  
of NaK.

3.120 ENGINEERING PROPERTIES OF POTASSIUM  
A. W. Lemmon, Jr., W. H. Mink, H. W. Deem, and E. H. Hall  
Battelle Memorial Institute  
Notes on Conference on Properties of Alkali Metals At BMI, April 1961  
The thermodynamic properties of K, and a study of materials of  
containment which includes Cb-1Zr alloy.

3.120 Liquid Metal Research (NDA)  
J. M. McKee, NASA TN-D-769, 1960.

Rocket-Nozzle cooling by Na, NaK - det. of O<sub>2</sub> content in Na -  
pumped Na loops. NSA 15:13286

3.120 Thermodynamic Analysis of Binary Liquid Alloys of Group  
IIB Metals. Pt. 3. The Solutions of Zinc, Cadmium, Indium, Tin,  
Thallium, Lead and Bismuth in Mercury. O. J. Kleppa. Acta  
Metallurgica, v. 8, July 1960, p. 435-445.

The heats of solution are determined calorimetrically at 150°. The relative partial enthalpies of Hg are compared with excess free energies obtained from the literature. 29 ref. (Pl2; Hg, Bi, Cd, In, Pb, Sn, Tl, Zn, 14-60)

3.120 THERMODYNAMIC PROPERTIES OF ALKALI METAL VAPORS AND MERCURY  
(R60 FPD 358-A)  
C. J. Meisl. Revised by A. Shapiro (GE-FPLD) 2nd Revision  
Nov 9, 1960. 179p

The thermodynamic properties of Na, K, Rb, Cs, Hg, and Li are presented for the saturated liquid, saturated vapor, and superheated vapor phases as a function of temperature in °F. The following properties are included: enthalpy, entropy, molecular weight, specific volume, equilibrium sonic velocity, frozen sonic velocity, equilibrium specific heat, frozen specific heat, and frozen isentropic exponent.

NSA 15:22739

3.120 INVESTIGATION OF NATURAL CONVECTION HEAT TRANSFER IN LIQUID SODIUM  
McDonald, John S. and Connolly, T. J.  
Atomics International, Canoga Park, Calif.  
Nuclear Science and Engineering, 8, 369-77 (Nov. 1960)

An experiment was performed to investigate the transfer of thermal energy by natural convection from molten sodium to a cold plate. A large tank of sodium was used to simulate a semi-infinite mass of sodium. A horizontal circular plate in intimate contact with the sodium surface was cooled by flowing tetralin which caused its temperature to be lower than the sodium bulk temperature. As a result, natural convection occurred in the sodium and thermal energy was transferred from the sodium to the plate. Data were collected at steady-state conditions for values of the Rayleigh number from  $4.8 \times 10^6$  to  $4 \times 10^7$ . It was found that the experimental results could be correlated by the expression  $Nu = 0.0785 Ra^{0.32}$ , where Nu is the Nusselt number, and Ra is the Rayleigh number. The calculated probable error in the Nusselt number given by this equation is 1.08, and the multiple correlation coefficient for the experimental results and the equation is 0.954. This result is shown to be consistent with the results of other investigators who used different fluids in physical systems somewhat similar to that used in this experiment with sodium.

NSA 15:5157

- 3.120 METHOD OF COOLING NUCLEAR REACTORS  
Kurt Diebner  
British Patent 841.533, July 20, 1960

A method is proposed for cooling a reactor with a mercury-gas mixture. The Hg is used at high pressures and the gas is used to remove heat when the reactor is first started. NSA 14:21108

- 3.120 Liquid Metal Cavitation Problems and Desired Research  
Hammit, Frederick G.  
ASME, Paper No. 60-HYD-13, 1960, 7 p.

Cavitation of liquid Na, K, Rb, Na-K alloys, Hg, Bi and PB-Bi alloys as heat-engine fluids versus  $H_2O$ . Temperature, density of liquid, density of vapor, viscosity, surface tension, heat capacity latent heat, thermal conductivity, vapor pressure and bulk modulus. Rev. of Met. Lit. 17:5.

- 3.120 "Heat Transfer to Sodium-Potassium Alloy in Pool Boiling," Chem. Eng. Progr., Symposium Ser., 56 (30), 251-59 (1960).  
N. Madsen and C. F. Bonilla

Film coefficients are presented for sodium potassium alloy (44 wt % K) boiling on a horizontal surface. The heat transfer at the boiling surface was calculated by subtracting the heat loss to the surroundings from the electrical input to the heater. Temperatures in the boiling liquid and vapor space above it were also determined. The best temperature differential for computing the heat transfer coefficient was found to be the difference between the boiling surface temperature and the equilibrium boiling point of sodium-potassium alloy at the pressure of the vapor space. A correlating equation was derived statistically for heat velocity as a function of pressure and temperature differential. NSA 15:8962

- 3.120 THERMODYNAMIC AND ELECTRICAL PROPERTIES OF MERCURY VAPOR AT PRESSURES BELOW ATMOSPHERIC AND HIGH TEMPERATURES  
(AFOSP-TN-60-657)  
A. Sherman and F. Martinek, Technical Note for Period Feb 1, 1959 to Feb 28, 1960. 43p. (G.E.)

Thermodynamic properties of mercury were calculated at temperatures up to  $15,000^\circ K$  and at pressures between 1 and  $10^{-4}$  atmospheres. The electrical conductivity was also calculated in the presence and absence of a magnetic field. Results are presented graphically.

NSA 14:23387

- 3.120 HEAT TRANSFER AND THERMODYNAMIC PROPERTIES OF MERCURY  
P. D. Cohn (AI) Nov 18, 1959. 29p. OTS

At present, no completely theoretical evaluation of the forced convection, boiling, or condensing properties of this metal have been successful. Evaluations of information on forced heat transfer, boiling, and condensing heat transfer coefficients, and thermodynamic properties of mercury vapor are presented. (NAA-SR-Memo-4666)

NSA 14:10573

- 3.120 CF-59-11-67, ORNL  
Thermodynamic Diagrams for Lithium, Sodium and Potassium.  
L. G. Epel and J. R. Simmons., Nov. 12, 1959, 9 p. OTS

Charts for the thermodynamic properties of lithium, sodium, and potassium in the wet and superheated vapor regions were prepared and are presented to facilitate thermodynamic cycle calculations. NSA 14:3846

- 3.120 NASA Memo 2-5-59 w  
Heat Transfer in a Liquid Metal Flowing Turbulently Through A  
Channel with a Step Function Boundary Temperature  
Poppendiek, H. F., Convair  
National Aeronautics and Space Administration  
Publications Announcements, No. 5, April 22, 1959  
March 1959,

An analytical heat-transfer solution is derived and evaluated for the general case of a turbulently flowing liquid metal which suddenly encounters a step-function boundary temperature in a channel system. Local Nusselt moduli, dimensionless mixed-mean fluid temperatures, and arithmetic-mean Nusselt moduli are given as functions of Reynolds and Prandtl moduli and a dimensionless axial-distance modulus. These solutions are compared with known solutions of more specific systems as well as with a set of experimental liquid-metal heat-transfer data for a thermal entrance region.

NSA 13:15594

- 3.120 Reactor Heat Transfer by Boiling Mercury-204  
Rohrmann, C. A.  
General Electric Co., Hanford Atomic Products Operation  
Richland, Washington  
HW-60564 Contract W-31-109-Eng-52  
1 June 1959, 29 p.

This report is a revised version of HW-56161. 204  
In order to emphasize the advantages of boiling Hg<sup>204</sup> as a reactor coolant, a liquid metal slurry fueled thermal reactor concept is studied in detail.

NSA 13:17212

- 3.120 AD 261775  
N. A. Nikol'skiy, N. A. Kalakutskoya, et al, "Thermophysical  
Properties of Certain Metals and Alloys in the Molten State,"  
MCL-714 of Voprosy Teploobmena, pp 11-45, 1959, Aerospace  
Technical Information Center WPAFB (27 Feb. 1961),  
(22 August 1961).

- 3.120 Literature Survey on Properties of Sodium Vapor  
Ervin, Guy, Jr.  
Atomics International, Div. of North American  
Aviation, Inc. Canoga Park, Calif.  
NAA-SR-Memo 4417 September 25, 1959, 13 p.

A literature survey was conducted to assess the adequacy of published data on the properties of sodium vapor and to obtain information to be used as a basis for recommending experimental work on further measurement of these properties.

NSA 14:18892

- 3.120 THERMODYNAMICS OF LIQUID Mg-Bi ALLOYS. J. J. Egan (Brookhaven  
National Lab., Upton, N. Y.). Acta Met. 7, 560-4(1959) Aug.

Thermodynamic studies on liquid Mg-Bi alloys were carried out using the emf method. A cell is described, suitable for measuring Mg activities in this system. Values of the excess partial molar free energy, the relative partial molar free energy, entropy, and enthalpy are listed along with the corresponding integral quantities. The results are compared with previous vapor pressure and calorimetric measurements as well as investigations of the phase diagram. Wagner's interpretation in terms of electronic constitution is consistent with the present data. (auth)

- 3.120 TID 3544  
A MOLTEN METALS HEAT CONDUCTIVITY CALCULATION. G. F. Butenko and  
M. I. Radchenko. Atonmaya Energ. 6, 205-7(1959)Feb. (in Russian).  
NSA 13:22448.

- 3.120 THE THERMODYNAMIC PROPERTIES OF LIQUID METALLIC SOLUTIONS OF POTASSIUM WITH THALLIUM, LEAD, AND BISMUTH  
Lantratov, M. F. and Alabyshv. A. F.  
V. I. Lenin Electrotech. Inst., Leningrad  
Zhur, Fiz. Khim. 33, 2429-34 (1959)

The thermodynamic properties of binary liquid alloys of K with Tl, Pb and Bi were studied by the e.m.f. method. In all cases there was observed a significant neg. deviation from Raoult's law which was attributed to the presence of structural groups of metallic compounds within the alloy. The large negative deviations in the excess entropy of mixing are related to the partial ionic nature of the bonds in the compounds. CA 54:21945h

- 3.120 "Heat Transfer by Free Convect. in a Liq. Metal,"  
F. J. Bayley et al, Proc. Roy Soc. (London) 265A 97-108 (1961)

An experimental investigation of the free convection H.T. process under special conditions associated with liq metal of high thermal cond. is described. By use of an apparatus employing the thermosyphon prin. and by means of wall temp measurements which avoided many of the difficulties often associated with liquid metals, data were obtained over a wide range of laminar and turbulent boundary layer flow. Results agree satisfactorily with existing theoretical data; in turbulent regions, they are a direct extrapolation of those from the laminar region, showing that molecular conduction remains the principal means of transferring heat even when there is significant macroscopic motion.

CA 56:14952e

- 3.120 Heat Exchange of a Plate in a Turbulent Boundary Layer of Incompressible Liquid at  $Pr \ll 1$ . E. D. Fedorovich (Polzunor Leningrad Central Turbine Construction Inst.).  
Inzhener. - Fiz. Zhur., Akad. Nauk Belorus.  
S.S.R. 2, No. 9, 3-11 (1959) Sept. (in Russian)

Results are presented of a theoretical and experimental investigation of heat exchange of a plate in liquid flow where the Prandtl number is much less than 1 (liquid metal). Measurements of the coefficient of heat transfer of a plate in a molten sodium flow was in satisfactory agreement with this calculation.

NSA 14:4421

- 3.120 CONTRIBUTIONS FROM THERMAL LATTICE DEFECTS TO THE EXPANSION OF SOLID AND LIQUID METALS. G. Borelius (Royal Inst. of Tech., Stockholm) Arkiv Fysik 16, 199-28 (1959).

A phenomenological analysis is presented on the contributions from thermal lattice defects to the expansion of solid and liquid metals.  
NSA 14:640

- 3.120 Heat Transfer in Tubes to Mercury and to a Sodium-Potassium Alloy  
Kirillov, P. L., et al.  
Atomnaya Energ. 6, 382-90(1959) April  
(in Russian)

Experimental and theoretical data on liquid metal heat transfer are analyzed. The design is given of the experimental installation, the experimental area, and the thermopair used for measuring the distribution of temperature in the liquid metal flow. It was found that oxygen contamination of sodium-potassium reduces the heat transfer coefficient. The results carried out in the absence of thermal resistance contact at the wall-liquid metal boundary agree with published data.

NSA 13:13868

- 3.120 Lykoudis, P. S. et al. (Purdue Univ., Lafayette, Ind.)  
Heat Transfer in Liquid Metals.  
Trans. Am. Soc. Mech. Engrs. 80, 653-66 (1958).

The problem of heat transfer in liquid metals is studied for the case of a fully developed turbulent flow in cylindrical pipes of constant diam., the fluid under consideration being heated (or cooled) by a const. and uniform heat input at the wall. In the analysis, the similarity theory between heat and momentum transfer is used. A theory is presented which gives the ratio of eddy diffusivities for heat and momentum transfer as a function of the Prandtl no. Heat transfer in liquid metals can be analyzed universally in terms of a dimensionless parameter called the "generalized Pecklet no." Temperature profiles are presented and the limiting cases for a generalized Prandtl modulus equal to 0 are studied. CA 52:8640

- 3.120 AD 266768, Atomic Energy (Selected Article)  
Translation of foreign articles. Includes turbulent flow heat transfer in liquid metals.

- 3.120 Free Thermal Convection of Mercury in a Closed Circular Tube in a Transverse Magnetic Field  
A. G. Smirnov (Soviet Physics--Tech. Physics, 1958,3,(7), 1429--1434 (published 1959) See M. A., 26,361

- 3.120 Martin, D. L.  
National Research Council, Ottawa, Can.  
Thermal Effects of the Martensitic Transition in Sodium  
Phys. Rev. Letters 1, 4-5 (1958) July 1.

Specific heat measurements were made on sodium by the method of continuous heating using a modified adiabatic apparatus. The experimental runs were made in the following sequence: (1) sodium sample cooled to 40°K and specific heat measurements made to 98°K; (2) sample cooled to 40°K and measurements taken up to 100°K; (3) sample cooled to 2°K and measurements then made from about 20°K; (4) sample cooled to 20°K and measurements made up to 92°K; (5) sample cooled to 40°K and measurements made to 84°K. The specific heat of the sample was plotted against temperature from 40 to 100°K. Anomalous deviations from a smooth curve are shown curve are shown for cases (3) and (4), resulting from the martensitic transition.

NSA 12:12467

- 3.120 Liquid Metal Heat Transfer Media  
Kutateladze, S. S. et al.  
Translation of Atomnaya Energ. Suppl. No. 2, 1958  
New York, Consultants Bureau, Inc. 1959, 152 p.

The thirteen chapters in this volume cover the following subjects: basic properties of liquid metals, application of liquid metal heat transfer media hydraulic resistance in the flow of liquid metals, turbulent heat transfer in liquid metals, heat transfer during flow in tubes, heat transfer during the longitudinal flow around a plate, heat transfer during transverse flow around cylinders, heat exchange during free convection, heat transfer during vapor condensation, heat exchange during boiling, heat-exchanging equipment, stability of heat-resistant materials in liquid metals, and instrumentation NSA 14:287

- 3.120 Heat Transfer of Molten Sodium Flowing Transversely Across a Single Cylinder  
Andre-evskii, A. A.  
Atomnaya Energ. 7, 254-6 (1959), September (In Russian)

The local heat transfer dependence on the flow rate, the distribution of heat transfer along a cylinder, and variations of the relative heat transfer coefficient across the cylinder are analyzed. The mean heat transfer in transverse flow across cylinders and tube systems is plotted.

NSA 14:1611

- 3.120 CEA-tr-R-565  
Echange Thermique Par Metaux Liquides (Thermal Exchange by Liquid Metals) Kutateladze, S. S., et al, Translated into French by B. Vinogradoff from Atomnaya Energ. 4, 422-36(1958). 43p. (Includes original, 17p.)

A review is presented on the studies of heat transmission between a solid surface and liquid metals. The results of investigations on the thermal exchange during discharge through long and short pipes and through slits, during flowing around bundles of rods or groups of plates, during transverse flow around cylinders by free convection, and by condensation of liquid vapor were discussed. The effects of addition substances on the intensity of the heat exchange were studied. Problems connected with boiling of the liquid metals as well as the effect of wetting on the hydraulic resistance and the intensity of thermal exchange were also considered. Some formulas which permit the calculation of the thermal exchange are presented.

NSA 13:9255

- 3.120 KAPL-M-WMP-1  
Knolls Atomic Power Lab., Schenectady, N. Y.  
THERMAL CONDUCTIVITIES OF GASES, METALS, LIQUID METALS  
W. M. Przbycin and D. W. Linde. August 6, 1957. 29 p.  
Contract W-51-109-Eng-52.

Graphs on the thermal conductivities of gases (air, Ar, CO<sub>2</sub>, CO, He, H<sub>2</sub>, Kr, Ne, NO, N<sub>2</sub>, O<sub>3</sub>, and Xe), metals (Al, Be, Inconel, X. Types 304, 347 and 446 stainless steel, Ti, U-Zr alloy, and Zircaloy-2), and liquid metals (Na and Na-K alloy) are shown. Densities of liquid Na and Na-K are included (NSA 12:1438)

- 3.120 ON THE ENTROPY OF SOLID AND LIQUID METALS  
Borelius, G.  
(Royal Inst. of Tech. Stockholm.) Arkiv Fysik 11, No. 5, 421-7 (1957).

A theoretically natural division of the observed heat capacity  $C_p$  values into a kinetic and potential part has been made.

- 3.120 Specific Heats of Liquid Metals and Liquid Salts by T. B. Douglas.  
First Nuclear Engineering and Science Congress 1, 191-199 (1957).

General method of measuring and important sources of error; specific heats of mixtures in relationship to those of their components.  
Metals Review, page 57, January 1958

- 3.120 Thermal Conductivity of Metals by C. T. Ewing et al.  
Paper from "Liquid Metals Technology." Part 1. Chemical Engineering Progress Symposium Series, p. 19-24. 1957

Develops a general thermal conductivity equation for metals based on the concept of electronic and molecular conduction; its application in the prediction of thermal conductivity values, degree of correlation for 140 metals and alloys over wide temperature ranges. Equation valid for both liquid and solid metals. 33 references. (AGN Lib. C-1 3-689)  
Metals Review page 42, March 1958

- 3.120 Specific Heats of Liquid Metals and Liquid Salts  
Douglas, T. B. (Nat. Bur. Standards, Washington, D. C.)  
Trans. Am. Soc. Mech. Engrs. 79, 23-8 (1957).

The general method of measuring specific heats of liquid metals and liquid salts at high temperatures is reviewed with the more important sources of error. Data for specific heats are examined on a volume basis, and 2 examples of the relation of the specific heats of mixtures to those of their components are presented. The specific heats of most liquid metals and liquid salts, when converted to an atmosphere basis, appear sufficiently alike to justify an approximate prediction in many cases for which no data exist, and for checking the probable validity of out-of-line experimental data. However, enough of the nitrates and hydroxides listed by D. have low at. sp. heats to justify treating these types of salts separately from the others. Other exceptions are noted. CA 51:4118

- 3.120 AERE-R/R-2190  
Firman, E. C. et al. (United Kingdom Atomic Energy Authority, Research Group. Atomic Energy Research Establishment, Harwell, Berks, England) Experience Obtained on a Liquid Sodium Heat Transfer Rig 1954/1956. August 1957. 31 pages

Heat transfer data for Na flowing at moderately low Reynolds number in a double annulus heat exchanger are reported. The results qualitatively confirm the findings of coefficients well below the theoretical minimum. Addition of an inert gas to the flowing liquid produced a pronounced lowering of the heat transfer coefficient. After some 1400 hr operation, deposits mainly of  $\text{Na}_2\text{O}$  occurred throughout the apparatus. It is shown that such deposits could be an important factor in depressing the heat transfer coefficient. It is not claimed, however that this is the only or principal factor. Other possibilities are commented upon. General operating experience is also described. The experiment included an investigation of the metallurgical changes occurring in a dynamic Na in stainless steel system and the results are compared with static controls.

NSA 12:5952

- 3.120 Low-Temperature Heat Capacities and Related Properties of Potassium and  $\text{Na}_2\text{K}$  by Krier, C. A. et al (Univ. of Pittsburgh, Pgh., Pa) J. Phys. Chem. 61, 522-9 (1957).

Const. pressure heat capacities between 12 and  $320^\circ\text{K}$  were given for K and  $\text{Na}_2\text{K}$ . The  $\text{Na}_2\text{K}$ -K eutectic point was  $-12.65^\circ$  and the incongruent melting point was  $6.90^\circ$ . The entropies at  $273.16^\circ\text{K}$  and  $298.16^\circ\text{K}$ , relative to abs. zero were 14.77 and 15.38 e.u./g.-atom for K and 12.48 and 16.07 e.u./g.-atom for  $\text{Na}_2\text{K}$ . A residual entropy for  $\text{Na}_2\text{K}$  at abs. zero was estd., assuming an ideal entropy of mixing, to be  $-0.05$  e.u./g.-atom. This value for the entropy of formation of  $\text{Na}_2\text{K}$  exceeds the ideal mixing entropy. No low-temperature transition anomalies of the type reported for Na, Rb, and Ca, were detected. Anomalous increase in heat capacity of  $\text{Na}_2\text{K}$  about  $100^\circ$  below the incongruent melting point, as found for the pure metals, indicates that the excess heat capacity is not caused by the open structure of the body-centered cubic lattice. The alloy deviates negatively from the Koop-Neumann rule below  $50^\circ\text{K}$  and in a pos. manner thereafter.

CA 51:12625

- 3.120 Heat Transfer Rates to Crossflowing Mercury in a Staggered Tube Bank by Hoe, I. R. J. and O. E. Dwyer (Brookhaven National Lab., Upton, N. Y.) and D. Dropkin (Cornell Univ., Ithaca, N. Y.) Trans. Am. Soc. Mech. Eng. 79, 899-907 (1957) May.

An experimental heat-transfer program has been under way for some time at the Brookhaven National Laboratory, the general purpose of which is to obtain and correlate heat-transfer coefficients for liquid metals flowing outside of tube banks. This paper covers one phase of the program; i.e., the measurement of heat-transfer coefficients for mercury flow normal to a staggered tube bank. The factors studied were linear velocity, tube location in the bank, circumferential variation of the local coefficient for a single tube, type of contact, i.e., wetting versus nonwetting, and pressure drop.

NSA 11:6709

- 3.120 The Resistance Discontinuity and Entropy of Melting of Some Metallic Elements, Knappwost, A. and F. Theime (Univ. Tübingen, Ger.) Z. Elektrochem. 60, 1175-80 (1956)

Electric conductivities of liquid and solid Al, Tl, Cd, Zn, and Hg at the melting point were determined. The data agree with a previously postulated relation between the resistance discontinuity and the entropy of melting. Deviations from the relation indicate a change in conduction-electron concentration on melting for Cd, which can be explained by use of Brillouin zones. The moderate decrease of resistance of melted Zn can be similarly explained. A decrease of conduction-electron concentration appears to occur when Hg melts; anomalies in the magnetic susceptibility of the electron gas confirm this conclusion.

- 3.120 THE USE OF SODIUM AND SODIUM-POTASSIUM ALLOY AS A HEAT-TRANSFER MEDIUM.  
W. B. Hall and T. I. M. Crofts. Proc. Inst. Mech. Engrs. 170, 321-39  
(1956).

A no. of Na and Na-K circuits which have been built and operated over the past 3 years for heat-transfer expts. are described. The design and construction of liquid metal circuits and the components which are commonly used in them are discussed.

CA51-7065h

- 3.120 NYO-6330  
Pittsburgh Univ., Application of Chemical Thermodynamics to the Study of Alloy Formation, Progress Report for Jan. 1, 1956 to April 1, 1956., Wallace, W. E. et al, 7 p., Contract AT(30-1)-647

Provisional heat capacity results are available for Zn (12 to 320°K) and Mg (20-270°K). Final results for Na<sub>2</sub>K (12-321°K) are available and are being prepared for publication in the Journal of the American Chemical Society. Assuming the liquid alloys to be formed with  $\Delta S$  = the entropy of random mixing, the entropy of Na<sub>2</sub>K at 0°K is 0.00 e.u./g. atom. Cp for Na<sub>2</sub>K rises above the Dulong-Petit limit as its (incongruent) melting point is approached in a fashion rather similar to the rise in Cp for the pure alkali metals near their melting point. NSA 11:2920

- 3.120 NYO-7638  
POOL BOILING HEAT TRANSFER WITH MERCURY. C. F. Bonilla, J. S. Busch, A Stalder, N. S. Shaikhmahmud, and A. Ramachandran. (Mar. 6, 1956). 24p. Contract AT(30-1)-1042. CU-11-56-AT-1042-Ch.E.  
\$4.80(ph OTS); \$2.70(mf OTS); Dep.(mc).

Hg was boiled on a horizontal low-C steel plate at pressures from 4 mm. of Hg to 45 lbs./sq. in. absolute, depths of 2 to 10 cm., heat velocities of 4,000 to 200,000 Btu/hr.sq/ft., and with and without wetting agent additions. The nature of the boiling and the necessary temperature differential were observed. AICHE No. 20, Vol 53, 1957, Liquid Metals Tech. (Part 1) AGN Lib. C.1-3-689

- 3.120 Thompson Products, Inc., Cleveland.  
Thermodynamic Properties of Mercury.  
Daniel P. Ross. Mar. 20, 1956. Revised June 17, 1957. 34 p.  
Project No. 798 (TM-777).

The thermodynamic properties of mercury as a material which can be used as the working fluid of a Rankine cycle are tabulated. Temperature-entropy and enthalpy-temperature diagrams are given. (NSA-13-1459)

- 3.120 Circulation in Liquid Drops (A Heat-Transfer Study)  
Calderbank, P. H. and I. J. O. Korchinski (Univ. Toronto, Calif.)  
Chem. Eng. Sci. 6, 65-78 (1956).

The continuous-phase heat-transfer coefficient was studied for drops of mercury and of bromobenzene balling through aqueous solutions of glycerol. A photocell and electronic counter were used to count the number of drops which ranged from 0.2 to 0.3 cm. in diameter for mercury and 0.386 to 0.540 cm. for bromobenzene. The continuous-phase temperatures was constant. The disperse-phase temperature change was a measure of the heat transfer. Internal circulation in the drops and drop oscillation cause the effective diffusivity to be greatly increased. Drop oscillation commences at a Reynolds number of about 200. Detailed run data are presented and compared with the literature.

CA 51:4065



- 3.120 Heat Exchange to a Flowing Vapor-Liquid Mixture in Horizontal Tubes  
Korneev, M. I. and B. N. Puganov  
Teploenergetika 3, No. 6, 39-44 (1956).

An experimental investigation was made where mixtures of Mg, Hg (liquid), and Hg (vapor) and H<sub>2</sub>O-air were led through horizontal pipes. It was found that the coefficient of heat exchange through the wall depends on the amount of heat, the inner diameter of the tubes, and the rate of flow of liquid and vapor. The flow rate at which equilibrium in heat exchange is established depends on the heat, tube diameter, and rate of flow of vapor. It was found that the best results were obtained if the vapor flowed 2-4 m./sec. Two empirical formulas are presented, one for the Mg, Hg; the other for a steam-air mixture. If the tubes are inclined, the maximum permissible rate of flow of the liquid must be decreased.

- 3.120 Advances in Chemical Engineering, Vol. I, Academic Press, N. Y.  
(1956) pp: 52-3. Drew, Thomas B. and John W. Hoopes, Jr.

In paper on "Boiling of Liquids" Section C, Liquid Metals:

Liquid metals have some desirable characteristics as heat transfer media. They have very low viscosities and high thermal conductivities. Thus circulation can be obtained with low power requirements, and temperature gradients through the liquid are rather flat. The high boiling points mean that liquid metals are usable at atmospheric pressure at high temperatures. Other liquids require pressure application if they are to be used at high temperatures. Data (L3) for four liquid metals are shown in Figures 26 and 27. The data of Farmer (F2) for mercury at vacuum are described as "preliminary" and may be subject to revision.

For the region of low  $\Delta T$  (say below 25°F) the liquid metals give high values of  $h$ . For example at a  $\Delta T$  of 10°F water gave  $h = 500$  Btu./(hr. ft.<sup>2</sup>). (F), mercury plus a wetting agent gave a 3000, and NaK gave an extrapolated  $h$  of about 20,000, all tested in the same equipment (L3).

Thus liquid metals in nucleate boiling are excellent heat transfer agents, being superior even to water. Water in turn is definitely superior to the other common nonmetallic liquids.

- 3.120 Heat Transfer and Thermophysical Properties of Molten Alkali Metals by Novikov, I.I. et al. Soviet J. Atomic Energy 4, 545-60 (1956).

An investigation was undertaken of heat transfer to molten sodium during turbulent flow in a round copper or nickel tube. An interpolation formula was obtained. Experiments were conducted to determine thermal resistance between liquid sodium and a solid wall of copper, nickel, and stainless steel. Methods were developed for measurement of viscosity, temperature conductivity and density of molten metals. Results are given for measurements of these physical parameters for molten alkali metals (sodium, potassium, lithium and the eutectic solution of sodium and potassium) in a broad interval of temperatures. NSA 11:5362

- 3.120 TID 3305  
REVIEW OF EXPERIMENTAL INVESTIGATIONS OF LIQUID-METAL HEAT TRANSFER.  
Bernard Lubarsky and Samuel J. Kaufmann. March 1955. 115p.  
(NACA-TN-3336).

Experimental data of various investigators of liquid-metal heat-transfer characteristics were re-evaluated using as consistent assumptions and methods as possible are then compared with each other and with theoretical results. The re-evaluated data for both local fully developed and average Nusselt numbers in the turbulent flow region were found still to have considerable spread, with the bulk of the data being lower than predicted by existing analysis. An equation based on empirical grounds which represents most of the fully developed heat-transfer data is  $Nu = 0.625 Pe^{0.4}$  where  $Nu$  represents the Nusselt number and  $Pe$  the Peclet number. The theoretical prediction of the heat transfer in the entrance region was found to give lower values, in most cases, than those found in the experimental work.

3.120

BNL-2446  
REACTOR HEAT TRANSFER INFORMATION MEETING HELD AT BROOKHAVEN NATIONAL  
LABORATORY, OCTOBER 18-19, 1954. Dec. 1955. 195p.  
 \$1.00(OTS); Dep.; Ind. Dep.; Dep.(mc).

The following unclassified papers, presented at the Reactor Heat Transfer Information Meeting in October, 1954, are included: Heat Transfer Rates to Cross-Flowing Mercury in a Staggered Tube Bank; Specific Heat of Liquid Metal and Salt Mixtures; The Effect of Gas Entrainment on the Heat Transfer Characteristics of Liquid Mercury; Flow in a Thermal Convection Harp in the Grashof Modulus Range From  $10^4$  to  $10^6$ ; Theoretical and Experimental Investigation of Heat Transfer by Laminar Natural Convection Between Parallel Plates; Remarks on Forced Heat Convection in Cylindrical Channels; Potential and Parabolic Velocity Distributions; High Temperature Liquids; Heat Transfer to Boiling Water Forced Through an Electrically Heated Tube; Boiling Density Studies in Multiple Rectangular Channels; Measurement and Prediction of Density Transients in a Volume-Heated Boiling System; Heat Transfer and Corrosion Tests for a Sodium-Cooled Fast Breeder Reactor; and Free Convection in Narrow Vertical Liquid Metal Annuli.

3.120

BNL-2433  
HEAT TRANSFER AND FLUID DYNAMICS IN MERCURY-WATER SPRAY COLUMNS.  
 R. D. Pierce (Babcock and Wilcox Co.), O. E. Dwyer, and J. J. Martin  
 (Univ. of Michigan). 1955. 39p. Submitted for  
 publication in Chem. Eng. Progr. NSA 13:11365

Heat transfer and fluid dynamics were studied in columns spraying hot Hg into rising streams of water. Volumetric and area heat transfer coefficients are presented. These coefficients are lower than those reported for heat transfer from fixed spheres. The major flow of water bypassed the drops while water surrounding the drops flowed downward. The principal heat-transfer resistance appears to lie between these rising and falling water streams. Outlet Hg temperatures did not approach inlet water temperatures as a limit because the flow patterns caused a discontinuous rise in the water temperature at the bottom of the columns.

3.120

NP-5727  
HEAT TRANSFER AND PRESSURE DROP WITH NaK-56 FLOWING PERPENDICULAR TO  
VERTICAL TUBES. Memo Report No. 87. M.J. McGoff and J. W. Mausteller.  
 July 29, 1955. 17p. Contract NObs-65426.

A cross-flow heat exchanger has been tested with liquid metal (NaK-56) as the heat-transfer fluid. The heat exchanger consisted of 25 1/2-in.-OD tubes arranged on a 5/8-in. equilateral triangular pitch; 5 rows longitudinal and 5 rows transverse to flow. Operation was up to 900 F at Reynolds numbers of 3000 to 80,000. Heat-transfer coefficients varied to the 0.8th power of the Reynolds number and were higher than have been reported for Hg or pressurized water. Friction factors agreed with those obtained for the more common fluids.

3.120

NP-5491  
FLOW DECAY IN A SODIUM HEAT TRANSFER SYSTEM. Robert A. Tidball and  
 F. L. Mangold. Jan. 11, 1955. 24p. Contract NObs-65426, Technical  
 Report No. 35.

Isothermal flow decay studies were made on the sodium side of the 1000 kw steam generating system, and the results compared with decays calculated by an analytical technique developed for SIR emergency cooling predictions. A total of eleven tests were run: seven at 800 to 850 F sodium temperature and four at 580 F sodium temperature. Initial flow rates of 75 and 50 gpm were used for each condition. In all cases there was a more rapid decay than predicted--at one second the flow was about 55% of the predicted flow.

3.120

UN - 639  
Heat Delivery of Molten Metals. M. A. Mikheyev, V. A. Baum,  
 K. D. Voskresensky, and O. S. Fedynsky. June 30, 1955.  
 10 p.

Heat transfer characteristics of molten metals vary considerably from those of the liquids normally employed for this purpose. Experiments to determine specific hydraulic and heat transfer data for Hg, NaK, and Sn are presented, in addition to the data obtained. 8 references.

- 3.120 NRL - 4506  
Thermal Conductivity of Mercury. C. T. Ewing, R. E. Seebold,  
J. A. Grand, and R. R. Miller. Mar. 17, 1955. 11 p.

The thermal conductivity coefficients of high-purity mercury have been measured from 150 to 540°C with longitudinal heat flow apparatus. The vapor pressure varied greatly over this range (less than atmospheric to over 25 atmospheres). However, an increase from 8 to 22 atmospheres in pressures at one temperature showed no change in the conductivity coefficients. The coefficients over the given range vary from 0.101 to 0.136 watts/cm<sup>2</sup>/cm. Lorentz values, while fairly constant, are somewhat higher than the theoretical values. Values of conductivity for the two sections of stainless steel bar used in the measuring unit gave values more widely separated than was contemplated.

- 3.120 ORO-139  
EFFECT OF GAS ENTRAINMENT ON THE HEAT TRANSFER CHARACTERISTICS OF MERCURY UNDER TURBULENT FLOW CONDITIONS. Final Report. Harold Chelemer, June 1955. 169p. Contract AT(40-1)-1310.  
\$1.00(OTS).

Data were obtained over a range of Prandtl modulus from 0.019 to 0.025, Peclet modulus from 115 to 15,200, Reynolds modulus from 2100 to 646,000, and Euler modulus from 0.58 to 26,000. Below a Peclet modulus value of 4200 the data obtained with reduced entrainment were considered representative, the test sections being considered hydraulically smooth in this Peclet range. These data were correlated by the equation  $Nu = 3.55 + 0.0179 Pe^{0.8}$  with an average deviation of 3.3%. Above a Peclet value of 4200 the data obtained with the 3/4-in. test section were correlated by the equation  $Nu = 0.544 Pe^{0.417}$  with an average deviation of 5.2%. Methanol heat transfer tests were conducted in the system, the experimental results being in excellent agreement with predicted results. The experiments substantiated the accuracy of the operating and calculation procedures used and supported the validity of the mercury heat transfer results. 60 references.

- 3.120 AD-212947  
Heat Transfer Experiments with Sodium Potassium Alloy  
Jenkins, A. E. and McKee, G.  
United Kingdom Atomic Energy Authority (Gt. Brit.)  
March, 1955  
(Declassified 1958) 6 p.  
(Report No. R&DB(W)TN-198)  
TAB U59-112643

A description is given of experiments in which the heat transfer coefficient between two annuli each carrying a flow of sodium potassium alloy were measured. For Peclet numbers above 60 the results are in good agreement with the theoretical values given by Lyon (R. And D. B. (W) rept. 8054). For Peclet numbers below 60 the results do not agree with theory but are of doubtful accuracy. Circumferential temperature variations caused by eccentric positioning of one of the tubes of the exchanger have been measured for varying degrees of eccentricity. The maximum values obtained are only a fraction of those predicted by the simple theory.

NSA 13:9253

- 3.120 Diffusion in Molten Metals. VI. Diffusion in the Tin-Bismuth System  
Niwa, Kichizo, Univ. Hokkaido, Nippon Kinzoku Gakkaishi 19, 299-302 (1955)

Diffusion coeffs. of Sn and Bi in the Molten Sn-Bi system were measured at 450-600° at comparatively low concns. of the diffusing metal. Diffusion coeffs. were estd. as consis. independent of concn. Thus  $D_{Bi} = 0.0013 \exp(-5000/RT)$  and  $D_{Sn} = 0.00052 \exp(-3200/RT)$  were obtained. These results showed that it was not atoms but cations that diffused in the Sn-Bi soln. because the activation energy of diffusion was of the same order as in nonmetallic solns. in spite of the great discrepancy between their energies of vaporization. The theoretical values of diffusion coeffs. which were calcd. roughly by the Stokes-Einstein equation were in good agreement with the expd results. Subsequently, the dependence of the diffusion coeff. of this system on the concn. was measured at 500° by using the Boltzman method (cf. Jost. Diffusions in Solids, Liquids and Gases 1951), 550 pp. (C.A. 45, 10031 d)). Diffusion coeffs. changed almost linearly with concn. Moreover, the product of diffusion coefficient and viscosity varied linearly with concn. of Bi. This was in agreement with the fact that thermodynamically the Sn-Bi system had ideal behavior.

CA 50:17853i

- 3.120 TID 3544  
TURBULENT HEAT TRANSFER FROM A MOLTEN FLUORIDE SALT MIXTURE TO SODIUM-POTASSIUM ALLOY IN A DOUBLE-TUBE HEAT EXCHANGER. D. F. Salmon.  
Nov. 3, 1954. Decl. July 16, 1959. 31p. (ORNL-1716) \$4.80(ph), \$2.70(mf) OTS. NSA 13:20496.
- 3.120 KAPL-1052  
FREE CONVECTION IN NARROW VERTICAL SODIUM ANNULI. D. P. Timo.  
Mar. 5, 1954, 31p. Contract W-31-109-Eng-52.  
Ind. Dep.

An engineering approach to the solution of a troublesome free-convection problem in the narrow vertical sodium annuli of the SRA Mark A rotating plugs is presented. Very high heat transfer rates (in the order of 2000 Btu/hr/ft of periphery) were observed in annuli approximately 0.1 in. wide, 30 in. high, and of varying diameters, with vertical  $\Delta T$ 's of the order of 200 F. An approximate analysis of the heat transfer in these annuli is made, based chiefly on the assumption that the maximum  $\Delta T$  between the hot and cold convecting legs of the tangential convection loops is equal to the vertical  $\Delta T$ . (The hot leg is at the heat source temperature, and the cold leg is at the heat sink temperature.) An expression giving the heat transfer due to free convection in a narrow annulus is derived, and a simple relationship between the Nusselt, Grashof, and Prandtl Numbers is obtained. The effectiveness of peripheral flow barriers or "piston rings" in reducing free-convection heat transfer in an annulus at higher  $\Delta T$ 's is conservatively evaluated. Preliminary experimental results provide a rough check on the analysis. This analysis, while made specifically for the case of convecting sodium, is applicable to other fluids, if film thermal resistances are taken into account.

- 3.120 AECU-2637  
HEAT TRANSFER TO LEAD-BISMUTH AND MERCURY IN LAMINAR AND TRANSITION PIPE FLOW. H. A. Johnson, J. P. Hartnett, and W. J. Clabaugh. Aug. 1953. 35p. Contract AT-11-1-gen-10, Project 5, Phase II.  
Trans. Am. Soc. Mech. Engrs. 76, 513-17 (1954); Dep.(mc).

Experimental heat-transfer results in the low Reynolds modulus range of 1,000 to 10,000 are reported for two different liquid metals, Bi-Pb eutectic and Hg. The single heat exchanger used in both series of tests was a 4/3-in., 18-gage, four-ft-long mild-steel tube. Similar heat-transfer tests with water in laminar and turbulent flow were performed with this same tube before and after each liquid metal series, and the agreement of the turbulent-water tests with previous published results support the liquid-metals test procedure. The experimental Nusselt values decrease from approximately 6 at Reynolds number of 10,000 down to 1 at a Reynolds number of 1,200 and are, consequently, considerably lower than the theoretical laminar-flow Nusselt value of 4.36. The data for both liquid metals, including flow in the upward and downward directions, are correlated on a Nusselt-Peclet basis with a single curve representing all experimental results with a maximum deviation of 20%.

3.120

NYO-3154

THE CONDENSING OF MERCURY AND SODIUM VAPOR AT ATMOSPHERIC AND LOWER PRESSURES. C. F. Bonilla and B. Misra. Nov. 1, 1954. 59p. Contract AT(30-1)-1042. CU-9-54-AT-1042-Ch.E. Proceedings of Heat Transfer Symposium sponsored by AIChE and ASME, Louisville, Ky., Mar. 20-23, 1955.

Heat-transfer coefficients were determined for Hg vapor condensing on both water and air-cooled vertical carbon steel, Cu-plated steel, Ni, type 304 and stainless steel condensers, 0.5 in. OD and 0.5 to 3 in. in length. Experiments were also carried out on a 4.5 in. long, 0.5 in. OD Ni--stainless steel composite tube condenser, both in horizontal and vertical positions. Visual observations, still photographs, and Fastax moving pictures showed film condensation on Cu-plated steel and Ni surfaces and dropwise condensation on stainless steel surfaces. On steel condensation was usually dropwise near the top and filmwise near the bottom. The heat velocity varied from about 25,000 Btu/hr/ft<sup>2</sup> at 0.5 psia with air cooling to about 750,000 at 15 psia with water cooling, while the heat-transfer coefficients ranged from ~ 3000 to ~ 10,000 Btu/hr/ft<sup>2</sup>/°F for film-type condensation and from about 4000 to over 100,000 for dropwise condensation. For measuring directly the temperature drop through the condensate film or from the vapor to the surface of the condenser, Fe-Hg and Ni-Hg differential thermocouples, as well as the Ni-stainless steel composition condensers themselves, were successfully employed. Condensing-heat-transfer studies for Na vapor were also carried out on a bi-metallic Ni--stainless steel condenser, using the condenser itself as its own thermocouple. The heat velocities varied from about 60,000 Btu/hr/ft<sup>2</sup> at 650°C to about 100,000 at 870°C, giving heat-transfer coefficients ranging from 11,000 to 13,000 Btu/hr/ft<sup>2</sup>/°F. The condensing-heat-transfer coefficients obtained for Hg and Na are only a small fraction of the Nusselt equation values for film-type condensation. 16 figures.

3.120

RDB(W)-8054

Heat Transfer Experiments with Sodium

Hall, W. B. and Jenkins, A. E.

Windscale Works, Sellafield, Cumb., England

June 1953, 19p.

The theoretical approach to the problem of heat transfer in liquid metals is briefly reviewed. The difference between this approach and that used in the case of fluids with a high Prandtl number is due to the fact that the thermal conductivity of a liquid metal may be so high as to swamp the "eddy conductivity" in a turbulent stream. A description is given of experiments in which the heat transfer coefficients between two annuli each carrying a flow of sodium were measured. Since a direct comparison with results obtained with a circular tube is not possible, the results are in quite good agreement with the theoretical values given. In the course of the work it was found that there were significant variations in temperature around the annuli carrying the liquid metal in the heat exchanger. It is thought that these variations were due to a slight eccentricity of the exchanger tubes. An approximate theoretical treatment indicates that such variations are likely to be greater (when expressed as a fraction of the overall temperature difference) in the case of liquid metals than in the case of fluids with a high Prandtl number. In these experiments, where the heat flux was about 50 watts per cm<sup>2</sup>, the temperature variations were quite small, but if full advantage is taken of the liquid metal to obtain high heat fluxes, they might be so large as to produce serious thermal stresses and distortion of the heat exchanger.

NSA 13:12925

3.120

NYO-6217

NATURAL CONVECTION HEATING AND COOLING BY HORIZONTAL CYLINDERS: FINAL REPORT. C. F. Bonilla and J. P. Collins. June 1, 1953 6p.  
CU-11-53 Dep.; Ind. Dep.

Heat transfer coefficients for natural convection at horizontal cylinders were measured in the heating and cooling of water, mercury, and 40% and 60% aqueous sucrose solutions. No significant difference between heating and cooling could be found for steady state results, but direction of heat flow had considerable influence on the unsteady state correlations.

3.120 NYO - 3100

A METHOD FOR MEASUREMENT OF THE SPECIFIC HEAT OF SODIUM VAPOR:  
(PROGRESS REPORT).

M. M. Makansi and W. A. Selke. Apr. 1, 1953. 21 p.

A method for the measurement of the specific heat of Na vapor at one atmosphere in the range of 200°C superheat, is presented. This method can be extended to include a wider range of temperatures and pressures; it also can be used for the determination of the specific heats of various other fluids of very high boiling point. The method is suitable at temperatures where the heat loss to the surroundings is appreciable compared to the sensible heat which can be transferred to a fluid stream in test equipment.

3.120 BNL - 259

QUARTERLY PROGRESS REPORT FOR JULY 1 - SEPTEMBER 30, 1953.  
UNCLASSIFIED SECTION). 57p.

Liquid Metal Heat Transfer. The objectives of this project are: (1) determination of the average film-heat-transfer coefficient for individual tubes in a tube bank for crossflow of Hg therein; (2) determination of circumferential variation of the coefficient around an individual tube; and (3) determination of pressure drop across the tube bank. With the completion of an automatic liquid-level control system, reasonably good pressure-drop data have been obtained. Pressure drops are about 5% below those expected on the basis of data on oil at lower Reynolds numbers and data on H<sub>2</sub>O at higher Reynolds numbers. This is believed due to non wetting of the stainless steel tubes by the Hg. Data obtained on tubes in the interior of the lattice show that, in general, the local coefficient is a maximum at the front of the tube decreases to a minimum at the rear of the tube, the rear value being 50% of that at the front. At a Reynolds number of 20,000, h varied from about 3000 Btu/(hr)(ft<sup>2</sup>)(°F) at the front of the tubes to about 1500 at the rear. Presently available data show that the average coefficient varies as the 0.55 power of the Reynolds number. At a Reynolds number of 80,000 h is about 5000. Liquid Metal and Heat Mass Transfer in a Spray Column. Hg and dilute amalgams have been selected for a study of simultaneous heat and mass transfer in a spray column. These metals will be dispersed in a non-metallic phase. Water and various organic liquids are being considered for this phase. Originally it had been planned to find a component which would dissolve as a pure solution in both phases. Since nothing was found to satisfy this requirement, a reaction between a metal dissolved in Hg and an oxidizing agent will be utilized for the mass-transfer study. The major heat-transfer resistance is expected to be in the nonmetallic phase. Preliminary calculations indicate that the heat-transfer rate will be so rapid that difficulty in obtaining good data is anticipated.

3.120 NP-4047

TECHNICAL REPORT 16 (ON) HEAT FLUXES FROM LIQUID METAL TO BOILING

WATER. E. C. King and R. A. Tidball. Aug. 8, 1952. Dec. Apr. 21, 1955. 22p. Technical Report No. 16

Steam has been generated on the outside surface of a specially designed fluted single tube in an exchanger with NaK flowing through the center tube and boiling water in the shell. The boiling surface area was 0.9815 ft<sup>2</sup> and the NaK flow rate approximately 6000 lb/hr. Steam was generated at pressures from 100 to 1200 psi with heat fluxes as high as 404,000 Btu/hr/ft<sup>2</sup>. The highest NaK temperature experienced was 1896°F and the highest temperature difference between the NaK and boiling water was 778°F. Over-all heat-transfer coefficients between 430 and 540 Btu/hr/ft<sup>2</sup>/°F were obtained.

- 3.120 NYO-3150  
BOILING AND CONDENSING OF LIQUID METALS. C. F. Bonilla. Oct. 24, 1952.  
6p. Dep.; J. Am. Chem. Soc. 74, 2352-3(1952).

Condensation data for Hg vapor on vertical low-C steel and 304 stainless steel tubes have been obtained at pressures from 2.3 to 15 lbs/in.<sup>2</sup>. Drop-wise condensation was always obtained. The film coefficient of heat transfer ranged from 700 to 1800 Btu/hr x ft<sup>2</sup> x °F, much lower than expected. Traces of inert gas may cause this effect, which is being studied further. A horizontal plate apparatus for the boiling of Na has been designed and is under construction.

- 3.120 NYO-3148  
BOILING AND CONDENSING OF LIQUID METALS; PROGRESS REPORT. C. F. Bonilla, J. S. Busch, H. T. Chu and B. Misra. Apr. 24, 1952. 12p.  
Contract AT(30-1)-1042.

Preliminary data have been obtained on the boiling at atmospheric pressure of a shallow layer of Hg on a horizontal iron-plated surface. The boiling film coefficient of heat transfer,  $h$ , ranged from 1600 to 8400 Btu/hr x ft<sup>2</sup> x °F. No film boiling was observed although a heat flow rate of 260,000 Btu/hr x ft<sup>2</sup> was reached. Hg vapor at atmospheric pressure was condensed on a short water-cooled vertical iron tube. Dropwise condensation was obtained, but seemed to impair the heat transfer, if anything, on account of the adherence of the droplets to the surface. Droplets ranged from 1 mm in diameter down to dust, and at intervals a slide would occur of all of the droplets on a given area. The condensing film heat transfer coefficients were very low, ranging from 220 to 530 Btu/hr x ft<sup>2</sup> x °F. They were apparently adversely affected by a mercury oxide film that built up on the surface, and/or by traces of noncondensable gas. More reliable data on the thermoelectric force of the thermocouple Fe-Hg have been obtained, which are approximately 10% higher than the previous results. The millivolts of a couple with its cold junction at 0°C and hot junction at  $t_3$ °C is given, up to about 400°C, by  $E = 0.01939 t - 8.835 \times 10^{-6} t^2 - 9.675 \times 10^{-9} t^3$ .

- 3.120 BNL - 219  
QUARTERLY PROGRESS REPORT FOR OCTOBER 1 - DECEMBER 31, 1952,  
UNCLASSIFIED SECTION. 56p.

Liquid Metal Heat Transfer. The purpose of this project is to determine film heat-transfer coefficients for flow of Hg normal to a staggered tube bank. The individual test elements consist of an electrical resistance heating unit inserted in a 1/2-in. OD tube. This heating unit consists of Ni chrome wire wound on a Pyrex tube over which is placed a Pyrex sleeve. This sleeve is collapsed onto the inner rod by being heated to the melting point. The electrical input to the heating element will be supplied by a 250-v d-c motor-generator set. The annulus between the heater and the tube wall is to be filled with Hg for better heat transfer. The outer tubes of the test elements will be of two types: 347 stainless steel and chrome-plated Cu. There are 11 test locations in the lattice of 70 tubes with one element at a time being active. The active elements will be rotatable. This will allow the local and average film coefficient of heat transfer to be obtained, as well as the variation of coefficient through and across the lattice. (p.32-3).

- 3.120 NYO - 3099  
QUARTERLY PROGRESS REPORT (ON) AN APPARATUS FOR THE DETERMINATION OF  
THE CRITICAL TEMPERATURE OF SODIUM. W. A. Selke and M. M. Makansi.  
Oct. 1, 1952. 11p.

A design of an apparatus for the determination of the critical temperature of Na is presented. The method is based on the difference between the electrical resistivities of Na vapor and Na liquid as a function of temperature. This difference should decrease as the critical point is approached and vanish when the critical is reached. Construction of the apparatus has started.

- 3.120 NP-4010  
HEAT TRANSFER TO MERCURY. D. L. R. Bailey, W. F. Cope and G. G. Watson.  
July 1952. 32p. Heat Div. Paper No. 13

The results of measurements of heat-transfer coefficients using a parallel-flow heat exchanger with Hg as the working fluid are reported. The measurements cover the whole range of turbulent flow from the critical up to a Reynolds number of about 100,000. The measured forced convection coefficients are compared with those calculated from existing empirical formulae (McAdams, Eagle and Ferguson) and with those calculated from the momentum-transfer and vorticity-transfer theories of turbulent flow and with such other measurements as are available. In all cases the agreement is poor; the reasons for this are discussed and it is concluded that the most probable reason is that, under the conditions of these measurements, the Hg did not wet the walls of the tube. Nevertheless the results should provide data from which a Hg heat exchanger could be designed to an accuracy of  $\pm 25\%$  for conditions under which no wetting takes place. If the Hg does wet the walls then the coefficient will be multiplied by a factor which is tentatively put at about three from a survey of all available information. This uncertainty emphasizes the urgent need for measurements under wetting conditions.

- 3.120 Liquid Metals; Thermal Conductivity Measurements. Curtis T. Ewing.  
Oct. 23, 1951. 9 p. (NP-3481; 3230-135A/51).

Results are presented of experimental measurements and calculations of thermal conductivity of stainless steel (type 304), Na, and Na-K alloy (56.5 wt. % K) at temperatures from 200 to 815°C.

- 3.120 NYO-564  
NATURAL CONVECTION TRANSFER PROCESSES, HEAT TRANSFER TO LIQUID METALS AND NON-METALS AT HORIZONTAL CYLINDERS. Seymour C. Hyman, Charles F. Bonilla, and Stanley W. Ehrlich. July 1, 1951. 30p.  
\$0.20(OTS); Dep.

Heat transfer by natural convection from a 1/2-in. diam horizontal cylinder to liquids was investigated. Fourteen liquids were employed, including the Pb-Bi eutectic, Hg, Pb, Bi, Na, and Na-K alloy. The Prandtl number of the liquids ranged from 0.0075 to 300. Both streamline and turbulent modes of flow were observed and equations to represent both were derived. Surface wetting had no appreciable effect on the heat transfer coefficient. A method for measuring the average surface temperature without interference with heat or fluid flow involved electroplating two different metals over the surface and measuring the thermoelectric potential developed between them.

- 3.120 NATIONAL BUREAU OF STANDARDS PROGRESS REPORT TO THE ATOMIC ENERGY COMMISSION JULY 1, 1950 to SEPTEMBER 30, 1950.  
Decl. Jan. 12, 1956. 31 p. (AEC-D 4009; NBS-P-28). \$4.80  
(ph OTS); \$2.70 (mf OTS).

Thermal capacities of Na-K alloys are included.

- 3.120 Makansi, Munzes, Selke, Bonilla, "Thermodynamic Properties of Sodium," J. Chem Eng Data 5, 441-52 (1960)  
NAA-SR-62, Thermodynamic Properties of Sodium, Inatomi, Parrish, (1950)

The enthalpy, H, entropy S, and specific volume of N<sub>2</sub> between 426.79 and 2600°K at 10<sup>-8</sup> to 50 atm were calculated from available data on the vapor pressure, specific heat, H, and S of Na. A new value, -16.840 cal/mole, was selected for the heat of dimerization D<sub>0</sub> of N<sub>2</sub> vapor, as that value which gave a minimum discrepancy between observed and calculated properties. The critical temperature was estimated by 7 methods to be 2570  $\pm$  410°K. The calculated thermodynamic properties were summarized in a temperature -S chart (Millier diagram) in engineering units.



3.120 ANL-4029  
THERMOELECTRIC EFFECT BETWEEN NaK AND NICKEL  
Irwin M. Rehn, ANL, 1949.

3.120 ANL-4458  
THE RELATIVE THERMAL CONDUCTIVITIES OF LIQUID LITHIUM, SODIUM, AND EUTECTIC NaK, AND THE SPECIFIC HEAT OF LIQUID LITHIUM  
F. L. Yagee and S. Untermyer, ANL, 1950.

Thermal conductivities determined by measuring the temperature difference along the length of a liquid column of constant cross-section when the heat input is known; specific heat of liquid Li determined by comparing the cooling rates in air of Li-filled and Al-filled thin-wall stainless steel capsules.

3.120 ANL-4274  
EXPERIMENTAL BREEDER PROJECT REPORT FOR THE PERIOD DECEMBER 1, 1948 THRU FEBRUARY 28, 1949. H. V. Lichtenberger. Apr. 12, 1949. Decl. Jan. 17, 1957. 34p.

The temperature drops which occur from fuel slug center to coolant stream are analyzed. Resistance to coolant flow was determined on the mock-up model of the reactor. Specific heat determinations for NaK were made over a temperature range of 130° to 290° C. The heat transfer characteristics of NaK alloy heated, vertical composite tube boiler were determined.

3.120 KAPL-M-LFE-4  
Knolls Atomic Power Laboratory, Schenectady, N. Y.  
Corrosion and Other Factors in the Application of Sodium to the KAPL Reactor. L. F. Epstein and C. E. Weber, Dec. 15, 1948. Decl. March 25, 1957. 38p. Contract W-31-109-Eng-52.

Data accumulated on the nature of the engineering and technological problems involved in the use of liquid Na as a heat transfer medium in a nuclear reactor are presented. Some possible solutions are included.

NSA 12:844

3.120 AECU-1199  
HEAT AND MOMENTUM TRANSFER IN TURBULENT FLOW OF MERCURY. Sheldon E. Isakoff and Thomas B. Drew. (nd). 25p.

It is found experimentally for mercury flowing vertically in a 1.5-in. tube in the Reynolds modulus range 36,700 to 373,000 that the ratio of the eddy diffusivity for heat to that for momentum varies directly with the 0.46 power of the Reynolds modulus and as a function of relative position in the cross section that is independent of Reynolds modulus. The velocity profiles for mercury agree essentially with those for other fluids. The temperature profiles are at variance with the predictions of Martinelli (Trans. Am. Soc. Mech. Engrs. 69, 947(1947)). The heat-transfer coefficients, although well approximated by the Martinelli-Lyon equations, increase more rapidly than those equations predict.

3.120 NP-5169  
HEAT TRANSFER WITH SODIUM-POTASSIUM LIQUID ALLOYS. Robert C. Werner, Earle C. King, and Robert A. Tidball. Dec. 5, 1949. 45p.

Over-all heat-transfer coefficients of 1000 to 2100 Btu/(hr)(ft<sup>2</sup>)(°F) were measured in a double-pipe heat exchanger using a 44 and a 77 wt. % K alloy of sodium and potassium. The data cover a temperature range of 300 to 1200° F and a velocity range of 1.5 to 12 fps in the center tube. A method is presented for separating the over-all coefficients into individual film coefficients. The coefficients calculated by this method, with the aid of the physical properties of sodium-potassium alloys presented, are then compared with the theoretical coefficients for liquids of low Prandtl number with very favorable results. Values of the individual film heat-transfer coefficients are found to vary from 2000 to 6000 Btu/(hr)(ft<sup>2</sup>)(°F) for the temperatures and velocities used. At temperatures up to about 1400° F, alloys of sodium and potassium will serve as excellent heat-transfer media because of their low vapor pressures, low viscosities, high thermal stability, high thermal conductivities, and melting points below room temperature.

- 3.120 THIRD QUARTERLY PROGRESS REPORT ON HEAT TRANSFER TO LIQUID METALS;  
DECEMBER 11, 1948, TO MARCH 11, 1949; LIQUID METALS RESEARCH PROJECT.  
Mark B. Moore (nd). 8p. (ME-Q-3).

Variation of surface coefficients in the range 1200 to 1900 Btu/sq ft/hr;  
heat transfer tube of a unit under construction (photograph).

- 3.120 AEC-tr-2016  
HEAT TRANSFER MEASUREMENTS WITH MERCURY. D. Elser. Translated by  
Ronald Kay from Schweiz. Arch. Wiss. U. Tech. 14, 330-6(1948). 18p.

Measurements of turbulent flow of Hg in a pipe were made in order to  
obtain experimental verification of laws concerning heat transfer in the region  
of very small Prandtl Numbers.

- 3.120 ORNL - 415  
Forced Convection Heat Transfer in Thermal Entrance Regions,  
Part 3, Heat Transfer to Liquid Metals. William B. Harrison.  
74 p. Contract W-7405-eng-36. \$0.60(OTS); Dep.

The heat transfer to liquid metals in turbulent flow within the  
thermal entrance region of circular tubes having uniform wall temperature  
was explored. Since liquid metals are characterized by high thermal  
conductivity, emphasis has been placed on analytical conduction solutions  
which neglect the contribution to heat transfer that is made by the eddy  
motion of a fluid in turbulent flow. Three solutions, which differ only in  
the postulated velocity distribution of the fluid have been selected for  
comparison. The postulated velocity distributions are: (1) uniform, (2)  
parabolic, and (3) velocity proportional to distance from the channel wall  
raised to the low when compared with the mercury data or the conduction  
solutions. In an effort to explain this observation, it has been shown  
that, if a nonwetted condition existed, the small test section diameter  
and the high thermal conductivity of sodium would combine to maximize the  
effects on the heat transfer. An attempt was made to corroborate the  
hypothesis of nonwetting with an experimental study of interfacial electrical  
resistance, but the results were inconclusive.

- 3.120 MDDC -342  
DETERMINATION OF THE THERMAL CONDUCTIVITY OF SODIUM-POTASSIUM ALLOY  
AT ELEVATED TEMPERATURES. Herbert W. Deem and H. W. Russell, June 5,  
1946. Decl. Sept. 27, 1946. 9p.

Thermal conductivity of an alloy consisting of about 50% Na and 50% K  
by weight was determined over a temp. range of approximately 100°C. Thermal  
conductivity of the alloy in watts cm<sup>-1</sup> cm<sup>2</sup> °C<sup>-1</sup> was 0.258 at a mean temp.  
of 100°C and 0.284 at a mean temp. of 500°C. Thermal conductivity increased  
linearly with temp.

- 3.120 NRL - P - 2958  
VAPOR-LIQUID EQUILIBRIA FOR MIXTURES OF ALKALI METALS (SODIUM  
POTASSIUM). Apr. 10, 1941. 6p.

Equipment and procedure are described for the determination of the  
system sodium-potassium at 1 atm. The results are tabulated.

- 3.120 Some Relationships in Heat Transfer to Boiling Mercury in Forced  
Convection  
Styrikovich, M. A. and Semenovker, L. E.  
AEC-tr-3868 Translated for Atomics International from  
Zhur. Tekh. Fiz. 10, 1331-9 (1940) 21p.  
NSA 14: 1609

The heat transfer to boiling Hg was studied in forced convection flow.

## 3.130 N62-15836

STUDIES OF LIQUID SODIUM BY INELASTIC SCATTERING OF SLOW NEUTRONS

Cocking, S. J. (A.E.R.E., Harwell, Gt. Britain) 1962.

International Atomic Energy Agency, Vienna (Austria)

A study is made of the near elastic peak to provide data on diffusive motion in the liquid state. The use of slow neutrons (wave lengths  $4.0 \text{ \AA} - 4.5 \text{ \AA}$ ) permits studying the region of small momentum transfer; in this region the coherent effects can be, to some extent, separated from the near elastic peak. Spectra of neutrons scattered by the solid and liquid states of sodium have been compared. In the spectra at energy transfer greater than  $\sim 4 \text{ mev}$ , incoherent scattering dominates. For the solid, this region of the spectrum may be calculated within the present experimental error using the frequency distribution given by Bhatia. The corresponding spectrum for the liquid is similar to that for the solid, suggesting that the frequency distribution of motions of the atoms in the two phases are similar to that for times less than  $\sim 1.5 \times 10^{-13}$  seconds. The experimental quasi-elastic peaks have been compared with predictions of the theory of Egelstaff and Schofield and values for the interaction time at three temperatures have been derived. The interaction time increased with increasing temperatures, suggesting the dominance of free diffusion in the liquid. At the highest scatter angles, where coherent effects appear in the quasi-elastic scattering, a test of Vineyard convolution approximation is made. It is shown that the approximation gives agreement with the observed data when the coherent effects appear at small energy transfers.

## 3.130 WASH 1026

Reports to the AEC Nuclear Cross Sections Advisory Group,

ORNL. Oct. 28-29, 1959. J. A. Harvey. 72p. OTS.

The cross section measurement programs at ANL, BNL, Columbia Univ., Duke Univ., HAPO, LASL, and ORNL are reviewed. Hg is included. (For preceding report see WASH-1021).

NSA 14:4784

## 3.130 TID 3544

POINT VALUE CROSS SECTIONS FOR THE MATERIALS H,  $\text{Li}^6$ , Be, B, C, F, Na, K, Cr, Fe, Ni, Zr, Gd, W, and Pb. C. W. Monroe, D. Pomeroy, and J. Ray. Sept. 1956. 72p. For Pratt and Whitney Aircraft Div. (NDA-57-27). \$15.30(ph), \$5.40(mf) OTS. NSA 13:11380

3.130 ACTIVITY TRANSPORT IN SODIUM-COOLED SYSTEMS.

Fred G. Haag (General Elec. Co., Schenectady, N. Y.).

Nucleonics 15, No. 2, 58-61 (1957)

The investigation and findings of a Na-cooled reactor made for atom redistribution in a system that has Na flowing in stainless steel. Transfer rates for isotopes ( $\text{Co}^{60}$ ,  $\text{Mn}^{54}$ ,  $\text{Ta}^{182}$ ,  $\text{Fe}^{59}$ , and  $\text{Cr}^{51}$ ) in stainless steel are given; these were found to be particularly sensitive to temp. and oxides. Ba additive (1 wt.% was found to be an effective inhibitor and substantially reduces the O transport.)

CA51: 10254d

## 3.130 LWS-30103

California Research and Development Co., Livermore, Calif.

Deuteron and Neutron Induced Activities in NaK Coolants

S. J. Horn. Feb. 1954. Decl. Feb. 26, 1957. 26p.

U. S. Government Research Report, Vol. 29, No. 1, p. 46

- 3.130 Scattering of Cold Neutrons in Liquid Metals and the Entropy of Disorder, Kothari, L. S. et al (Atomic Energy Establishment, Bombay, India). Phil. Mag. (8) 1, 560-7 (1956) June.

Introducing a varying degree of disorder in Mott's quasicrystalline model of liquid metals, the change in the cold neutron scattering cross section of melting is calculated. Mott's calculations of the change in electric conductivity on melting have been repeated on the basis of this modified model using more recent data on the latent heat of fusion. It is shown that the change in the neutron scattering cross section in lead and the change in conductivity in sodium and potassium on melting can be explained if we assume that the entropy of disorder on melting is nearly  $0.5R$ ,  $R$  being the gas constant. That this value is of the right order of magnitude seems to be corroborated by self-diffusion data. CA 51:8603 also NSA 10:11204

- 3.130 The Isotope Effect of a Direct Electric Current Through Liquid and Solid Metals  
Haeffner, E., Th. Sjoborg. and S. Lindhe  
Z. Naturforsch. 11a, 71-5 (1956). January

The isotope separation effect of a direct electric current in a liquid metal is demonstrated by passing a current through mercury, which is enclosed in a capillary tube. The second part of the paper deals with an attempt of establishing an isotope effect when a direct current is passed through a uranium wire.

- 3.130 Preparation of Pure Mercury Isotopes from Natural Mercury by Mercury Photosensitization  
Pertel, R. and H. E. Gunning (Illinois Inst. of Tech., Chicago)  
J. Chem. Phys. 26, 219 (1957) Jan. NSA 11:3942

- 3.130 NDA-Memo-14-92  
Nuclear Development Associates, Inc., White Plains, N. Y. .  
Activation of Sodium Coolant. H. Yamauchi, June 22, 1955. 3 p.  
For Atomic Power Development Associates, Inc.  
NSA 12:4462

- 3.130 LWS - 24734  
RADIOACTIVITY OF RECYCLED LIQUID METAL COOLANTS. W. E. Drummond.  
Jan. 30, 1953. Decl. Mar. 29, 1957. 3p. CRD-R-23

In order to determine which liquid metal coolant is the most desirable from the shielding standpoint, sample calculations were made to determine the thickness of concrete needed to shield a semi-infinite pool of the material. These calculations were made for Na, K, Pb, Bi, Sn, and Hg.

- 3.130 LWS - 24338  
CONTAMINATION OF NaK COOLANT IN BARE THORIUM TARGET. L. M. Litz  
and R. E. Batzel. Mar. 13, 1952. Decl. Apr. 2, 1957. 18p.  
(CRD-T2C-87)

The nature, magnitude, and sources of activities to be expected in the NaK coolant of the Th primary target for the Materials Testing Accelerator were estimated. The primary target consisted of bare Th plates inserted in a stainless steel tube bank with molten NaK as coolant. The major source of activity will be due to nuclear reactions induced in the NaK by the incident deuteron beam and slow neutron flux; fission-product recoil activities will be a secondary source of activity.

- 3.130 ORNL-1161 (Del.)  
METALLURGY DIVISION QUARTERLY PROGRESS REPORT FOR PERIOD ENDING OCTOBER 31, 1951.  
W. H. Bridges, ed. Apr. 21, 1952. Decl. with deletions Nov. 12, 1959, 56 p., Contract W-7405-eng-26. OTS.

... The diffraction of neutron by liquid metals was attempted to gain information on the structure of metals. NSA 14:7700

### 3.140 CHEMICAL PROPERTIES

- 3.140 TID-7626 (Part 1)  
STUDIES ON SOME PHYSICO-CHEMICAL PROPERTIES OF LIQUID METALS  
AND DILUTE LIQUID METAL SOLUTIONS.  
S. W. Strauss, (NRL)  
NASA-AEC Liquid Metals Corrosion Meeting, December 14-15, 1961  
Brookhaven National Laboratory, Upton, Long Island, N.Y.

An analysis of solubility, viscosity, surface tension, and density data taken from literature. Equations have been formulated for use in thermodynamic considerations. (AGN Lib. 2-2786)

- 3.140 POLARIZATION AND TRANSPORT OF OXYGEN IN LIQUID SODIUM  
B. A. Nevzorov  
Zhur. Fiz. Khim., 35:620-3 (March 1961) (In Russian)

Polarization and anodic transport of oxygen are revealed on passing a 2 amp direct current through liquid Na at 300°C from 1 to 6 hours. It is shown that in different runs the amount of transported Na for 1 amp/hr is practically constant. The mean transport number of oxygen for uni- and divalent ions is calculated. It is proposed that the divalent oxygen ion in the form of a solvated complex is the one to polarize and to be transported. The assumption is also made that all liquid metals facilitate the dissociation of polar molecules of dissolved nonmetallic impurities.

NSA 15:19392

- 3.140 Thermodynamics and Models of Metallic Solutions. Richard A. Oriani. Paper from "The Physical Chemistry of Metallic Solutions and Intermetallic Compounds, Symposium" v. 1. Chemical Publishing Co., Inc., New York, 1960, p. 152-164.

Review of thermodynamic data on solid and liquid metallic solutions; concordance of existing statistical and elastic interaction theories with experiment. 41 ref. (Pl2; 14-67, 14-60)  
Includes Pb, Bi, Hg

- 3.140 Thermodynamic Properties of Liquid Solutions in the System Potassium-Mercury, Lantratov, M.F. and Tsarenko, E.V.  
Zhur. Priklad. Khim. 33, 1539-46 (1960) CA 54:21946i

The thermodynamic properties of the K-Hg system were detd. at 250-350° by measuring the e.m.f. of the cell K/solid electrolyte contg. K<sup>+</sup>/K-Hg. In the N<sub>K</sub> range from 0.04992 to 0.898 large pos. deviations of the activity of K and neg. deviations in the activity of n<sub>g</sub> were noted. This was ascribed to the formation of KHg<sub>2</sub>. The exothermic effect of formation reached a max. of -4.3 kcal./atom. at N<sub>K</sub> = 0.36. The max. free energy, -4150 cal./atom. was at N<sub>K</sub> = 0.365 at 325°. At this temp.  $\Delta S$  changed from -0.117 at N<sub>K</sub> = 0.1 to -0.301 at N<sub>K</sub> = 0.3 and to +0.518 at N<sub>K</sub> = 0.9.

- 3.140 "Removal of Molten Na from Reactor Coolant Systems,"  
L. Silverman and R. A. Sallach., Ind. Eng. Chem. 52 231-2 (1960).  
HB-40 (Monsanto Chemical Co.) a mixture of partially hydrogenated terphenyls is inert, has a greater density than that of Na(l) at temperatures between 120-140°, and tends to de-wet Na in contact with SS. It is used under a precautionary blanket of N to displace Na from inaccessible spots. Tenacious or emulsified Na can be destroyed safely by adding BuOH which dissolves Na butylate and is not excessively corrosive. Na coated with carbonate will require steam and dil. acids for removal. No inflammable or explosive materials are formed and the HB-40 is reusable.

CA 56:3090g

3.140 NAA - SR - 5687

The Compatibility of Kerosene with Sodium in a Closed System to 1200°F

Wolten, G. M. and Meyer, R. A., Atomics International, Div. of North American Aviation, Inc., Canoga Park, California  
1 November 1960, 15 p. Contract AT-11-1-GEN-8

The purpose of this investigation was to ascertain the suitability of kerosene or kerosene-like materials as coolants for sodium freeze seals in sodium-cooled nuclear reactors. The following facts were established. Different kerosenes are of different chemical composition, resulting in markedly different behavior toward sodium and heat. Certain possible constituents of kerosene form air-reactive compounds with sodium. The concentration of these ingredients was found to be very small in one type of kerosene and larger in another. Clues to the nature of these ingredients were obtained, and a possible method of eliminating them was suggested. The thermal stability of paraffins appears to be higher for branched than for straight-chain structures. In order to arrive at a specification for a safe type of kerosene to use in the intended application, the chemical composition of kerosenes would have to be established in greater detail. It seems entirely feasible, and it is recommended, that a suitable kerosene be selected on the basis of empirical tests similar to those developed in this work.

NSA 15:2565

3.140 CRYSTALLIZATION FROM DILUTE METAL SOLUTIONS

L. Benjamin and R. F. Strickland-Constable  
(Acta Met., 1960, 8 (6), 362-372)(In English)

The nucleation and crystal growth from soln. of Zn and Hg were studied by emf measurements. The rate of nucleation approx.  $\propto \exp(-\text{const} - \Delta T^2)$ , stirring increasing the nucleation rate by  $\sim 5x$ . These rates are  $\gg$  those reported by Hollomon and Turnbull ("The Solidification of Metals and Alloys," New York: 1951, 1; MA, 19, 383), and it is suggested that such high rates are due to the breeding of nuclei rather than heterogeneous nucleation. 10 ref--B.H.

MA 28:446

3.140 TRANSPORT PROCESSES IN LIQUID ALLOYS. II. THE ELECTRICAL FORCE ON AN ION

Paul C. Mangelsdorf, Jr. (Univ. of Chicago)  
J. Chem. Phys. 33, 1151-61 (1960) Oct.

The electrolytic migration velocities of impurity ions in liquid metals suggest the existence of strong net electrical forces on these ions, although other mechanisms are possible. On the basis of a detailed model of a liquid metal, the early theory of Skaupy is revived and revised. In dilute solution a total electrical force, proportional to the conductivity increment produced by a solute, is exerted on the solute and on nearby solvent when the electric field is applied. The part of the force on the solute ion may be opposed to the part on the solvent. Implications for the resistivity of liquid alloys are discussed, including a possible effect in very dilute solutions when the solutions are further apart than one mean free path. The effective number of free electrons in pure liquid mercury is provisionally estimated to be 0.3 per atom.

NSA 15:1396

3.140 The Estimation of the Activities in Binary Liquid Metallic Alloys.

Etienne Bonnier and Pierre Desre (Ecole Nationale Supérieure d'Electrochimie et d'Electrometallurgie, Grenoble, France)  
Compt. rend. 249, 1664-6 (1959) Oct. 28. (In French)

The methods for the estimation of the activity using the phase diagrams can be made more accurate by the knowledge of the enthalpies of the mixture. The Lunsden theory permits the derivation of a formula using these data. The formula is applied to the liquid system Na-K.

NSA 14:2750

Solubilities of Selected Metals in Mercury: Hermex Process

Messing, A. F., Dean, O.C.

(U.S. Atomic Energy Commission Rep., 1960,

The solubilities of U, Th, Gd, Sm, and Nd in Hg were determined from 25 to 356°C to evaluate the feasibility of the Hermex process as a method for fuel processing. Equations of the form  $\log. \text{solubility (wt.-%)} = a + b/T$  were developed for these metals. Integral heats of soln. were calculated for each. The solubilities of Ru, Pd, Zr, and Mo in Hg saturated with U were also determined; however, the low solubility of Zr and Mo gave soln. with a concn. below the limit of detection in the analytical method used, and therefore their values are reported as an upper solubility limit. U solubility in a 0.1 wt.-% Mg amalgam was  $1.2-1.5 \times$  Hg alone. When U and Th were present in the same Hg soln., their solubilities were mutually depressed. 19 ref.--R.J.J.

MA 28:348

NSA-14:17931

Experimental Investigations of the Removal of Sodium Oxide from Liquid Sodium

Billuris, G.

General Electric Company, Atomic Power Equipment

Dept., San Jose, Calif.

GEAP-3328, January 18, 1960, 57p. Contract N8-S-452

for Atomics International, Div. of North American Aviation, Inc.

Information was obtained on the growth and characteristics of sodium oxide deposits in liquid sodium which could lead to system plugging, and the removal of sodium oxide from molten sodium by the cold trap method was studied. The data confirmed that the deposits are formed more rapidly with an increased amount of oxygen in the sodium, cooling of the deposit area, and fluid agitation. In general, the deposits at 300 F appeared to be silver in color with patches of liquid adhering to irregular crystalline-like structures. At room temperature the deposits were relatively hard and brittle and broken pieces of the structure appeared porous. During operation of the purification loop the apparent rate of solution of sodium oxide in sodium appeared to be much slower than the rate of removal in the cold trap. The data from the cold trap deposit indicated that up to 20 vol. % sodium monoxide could be collected in the trap before significant flow restriction was apparent. The most effective packing material tested was knitted wire mesh. With any of the packings tested, and operating with a residence time of about 8 minutes or longer, the effluent sodium from the cold trap did not appear to be supersaturated with oxygen.

NSA 15:3957

Vaporization of Compounds and Alloys at High Temperature

Goldfinger, Paul, et al.

Free U. of Brussels, Belgium, Final Technical Report,

Jan. 1959, 59 p., AD 212 980, Div. 4; AFOSR TR-59-32

Contract AF 61(052)19, TAB 15 August 1959: 3988

The vaporization of ZnS, CdS, HgS, CdSe, HgSe, CdTe, HgTe from 400 to 1175 K, of sulfur, selenium, tellurium from 350 to 600 K, InAs, GaP, GaSb from 900 to 1250 K and of an iron-nickel alloy from 1400 to 1600 K have been investigated. The molecular composition of the vapor in equilibrium with the solid compounds (except for GaSb which in part of the experiments is liquid) has been determined. No molecules containing both elements of the compounds are present in the vapor phase at a measurable concentration ( $10^{-3}$  or less). The change in free energy, heat content and entropy for the vaporization processes have been measured and permit the calculation of thermodynamic properties of the compounds investigated. The vapors contain the group V and group VI elements in the form of different polyatomic species; equilibria between these species have been observed and the relevant thermodynamic quantities measured:  $D(\text{Te}_2) = 49 \pm 2 \text{ Kcal}$ ;  $D(\text{As}_2 - \text{As}_2) = 65 \pm 2 \text{ Kcal}$ ;  $D(\text{Sb}_2 - \text{Sb}_2) = 62 \pm 1 \text{ Kcal}$ ;  $D(\text{S}_2 - \text{S}_2 - \text{S}_2) = 61 \pm 7 \text{ Kcal}$ ;  $S_{330}(\text{S}_6) = 100 \pm 8 \text{ e.u.}$  Preliminary experiments on the evaporation of an alloy show that this method can give useful information on thermodynamic properties, especially on activities of the components.

- 3.140 RESISTIVITY AND KNIGHT DISPLACEMENT IN LIQUID SODIUM ALLOYS.  
E. Daniel (Physique des Solides, Paris) Phys. and Chem.  
Solids 13, 353-5 (1960) June. (In French)

A model developed for dilute solid solutions of elements of different valences is applied to liquid alloys of elements of the same valence. The model gives values for the resistivity and the Knight displacement simultaneously and in good agreement with experiment for alkali metal alloys. The model does not apply when the electronegativity of the solute differs appreciably from that of the solvent. This suggests that one should in this case consider as a whole the dissolved atom and its nearer neighbors, the electron clouds of which should be strongly perturbed. NSA 14:22069

- 3.140 Thermodynamic Properties of Liquid Metallic Solutions of Potassium and Bismuth, Lantratov, M. F. and Soloveva, M. I., V.I. Ul'yanov  
Electrotech. Inst., Leningrad Zhur. Priklad. Khim. 32, 304-8  
(1959) cf. C.A. 49, 1417H.

The e.m.f of concn. cells K (glass) K + Bi melt was detd. at 575° in an Ar atm. The activity of molten K-Bi solns. exhibit high neg. deviations from ideality. Thus, in solns. with  $N_K = 0.5$ ,  $a = 1.74 \times 10^{-6}$ .  $a$  of Bi is completely in the area of neg. deviation, so that the activity coeff.  $\gamma_{Bi} < 1$ , the results support the suggestion (loc. cit.) that there is a relation between the form of the activity isotherm and the compn. of the compd. formed,  $K_3Bi$ .

CA 53:10913a and NSA 13:14569

- 3.140 Determination of the Solubility of Oxygen-Bearing Impurities in Sodium, Potassium, and Their Alloys  
Williams, D. D., et al  
Naval Research Lab, Washington, D. C.  
J. Phys. Chem. 63, 68-71 (1959); cf. C. A. 51, 10195c

The compds. resulting from partial oxidation of K and Na metal were isolated and identified as the respective monoxides. The equil. oxide in a Na-K-O system was  $Na_2O$ . The solubilities in the following systems were detd. as a function of temp:  $Na_2O$  in Na, K, and Na-K alloys;  $K_2O$  in K, NaOH in Na, mixed NaOH- $Na_2O$  in Na, and  $Na_2CO_3$  in Na. Pos. errors in oxide content may result from failure to account for each species of impurity if sepn. and analysis of a sample depends solely upon total alky. calcn.

CA 53:7855b

- 3.140 THERMODYNAMIC ANALYSIS, XIII, ACTIVITIES, SEPARATION AND EVAPORATION EQUILIBRIUM IN LEAD-CADMIUM MELTS  
Schurmann, Eberhard, Bergakad, Clausthal, Germany  
Arch. Eisenhutthew 30, 40-9 (1959)

A theory is derived to check the graphically detd. and calorimetrically measured values of previous measurements. From the application of this theory it could be deduced that the behavior of both Pb and Cd in their melts is largely detd. by a tendency to sep. Which causes the super-cooled melts to form 2 layers at temps. slightly below that of the liquidus line at the Cd side. In the evapn. equil. the Cd shows a vapor pressure that is by 5 powers of ten greater than that of Pb, so that from a Pb-Cd melt with only 17 at. % Cd, a 900° and an external pressure of 1 atm., practically pure Cd evapd. with only 0.04 at. % Pb. An example of the application of the theory is given.

CA 53:7746c

- 3.140 SODIUM-WATER REACTION RATE STUDIES. L. Corrsin, H. Steinmetz, and B. Marano. May 15, 1959. 32p. (NDA-84-19) \$6.30(ph), \$3.00(mf) OTS.

NSA 13:13225



- 3.140 Thermodynamic Properties of Liquid Metal Solutions in the Sodium-Lead System  
Lantratov, M. F., V. I. Ul'yanov-Lenin Electrotech. Inst. Leningrad  
Zhur. Neorg. Khim. 4, 2043-5 (1959)

The thermodynamic properties for liquid metal Na-Pb solns. were calcd. from the values of the e.m.f. and its temp. coeff. cell: Na/electrolyte contg.  $\text{Na}^+/\text{Na}/(\text{N}_{\text{Na}} + \text{Pb}(\text{N}_{\text{Pb}}))$ , where  $\text{N}_{\text{Na}}$  and  $\text{N}_{\text{Pb}}$  are the at. atms. of Na and Pb. Measurements were made for  $\text{N}_{\text{Na}} = 0.05 - 0.9$  for 400-600°. The following properties were calcd.: activity, coeff., partial molar isobaric isothermal potentials, overpotential for Na and Pb, molar entropies, heat of mixing. Significant neg. deviations were observed from the laws for ideal solns. which become larger with a decrease in temp. This was attributed to the existence of structural groups of metallic compds. in the liquid phase. The extremes on the integral curves occur at  $\text{N}_{\text{Na}} = 0.5-0.6$ . The formation of Na-Pb alloys is exothermal; max.  $H = -4.25$  kcal./g. atom. The neg. values, which were obtained for the integral molar entropy of mixing of  $\text{N}_{\text{Na}} = 0.8-0.23$  indicate the nature of the bond for Na-Pb compds.

CA 54:11674e

- 3.140 Thermodynamics and Properties of Liquid Solutions. O. J. Kleppa.  
Paper from "Liquid Metals and Solidification". American Society  
for Metals, 1958, p. 56-86.

Application of thermodynamic theory to study of liquid metal systems. Experimental method of deriving thermodynamic information including phase equilibrium, chemical equilibrium and calorimetric methods. Data on heat of mixing and excess entropy of various binary solutions. 35 ref. (Pl2, 14-60)

- 3.140 ANL-6477  
CHEMICAL-METALLURGICAL PROCESSING  
Steunenberg, R. K., Burris, L. Jr., et al.  
(Argonne National Lab. Illinois)

Pyrometallurgical development is reported on melt refining, processes utilizing liquid metal solvents, supporting chemical investigations, and supporting engineering studies in liquid metal systems. The design and construction of fuel processing facilities for EBR-II are described. Research progress is reported on solubilities in liquid metals, coprecipitation studies, liquid-liquid metal distribution studies, and thermodynamic studies.

- 3.140 Thermodynamic Properties of Liquid Metallic Solutions. II.  
The Bismuth-Indium System  
Terpilowski, Janusz, University Wroclaw, Poland, Arch. Hutnictwa 3,  
226-37, (1958) (English Summary)

cf. C.A. 53, 7823a--E.m.f.s., E, of cells in (liquid) LiBr + KBr eutectic mixt. + InBr BiIn liquid mixt., were measured (cf. loc. cit.; C.A. 51, 17378c) in Ar atm. The cell is described in detail. The liquid alloy compn. (In at. %), E at 400°, and E at 500° (mv.) were: 5, 296.51, 326.03; 10, 240.15, 262.86; 20, 176.12, 191.95; 30, 133.79, 145.59; 40, 94.32, 103.29; 50, 66.10, 72.91; 60, 46.47, 51.49; 70, 29.97, 33.48; 80, 18.64, 20.83; 90, 7.53, 8.57; and 95%, 3.88, 4.38; resp. E was reproducible within  $\pm 0.5$  mv. and varied linearly with temp. Activities and activity coeffs. for 400 and 500°, and excess total and partial molar enthalpies, entropies, and Gibbs free enthalpies, and tabulated and plotted vs. compn. Deviations from Raoult's law were neg. and decreased with temp.

CA 53:5833f

- 3.140 AD254791 The Role of  $\text{O}_2$  in the Brittle Behavior of Metals by  
E. S. Fankins, Prog Rep 4 A.M.L., Naval Air Mat'l Center, Phila. Pa.  
TED No. NAM RS 7045

Equilibria in the following reaction was investigated in the temp range of 1460-1700°C.  $\text{H}_2 + \text{O}$  (in liq metal)  $\rightarrow \text{H}_2\text{O}$ . The max solubility of the Oxy in the Liq Metal was determined. These results are discussed as well as the eq. for max % of  $\text{O}_2$  in the different metals. A summary of visits to various labs in Europe is also reported.

- 3.140 Diffusion and Chemical Control in the Dissolution of Metals in Mercury, Bennet, J. A. R., and J. B. Lewis  
J. Chim. Phys., 55:83-89; discussion 89-90 (1958)

The const. of dissolution of Pb, Sn, and Zn in Hg were compared with those of the dissolution of benzoic acid in water since the latter is known to be a process of controlled diffusion. The correlation between the data from the systems Sn-Hg, Pb-Hg, and benzoic acid-water, was sufficient to establish that the rates of dissolution of Sn and Pb in Hg represent a controlled-diffusion process. With Zn-Hg, dissolution is partly a chem. process and it was shown that, with single, cylindrical Zn crystals, the rate of dissolution was different for the different crystallographic faces. The same phenomenon was qual. observed with Bi and Cd. --J.S.C.

MA 26:663

- 3.140 Bronstein, H. R. et al. (Oak Ridge National Lab., Tennessee)  
The Electrical Conductivity of Solutions of Alkali Metals in Their Molten Halides, J. Am. Chem. Soc., 80, 2077-81 (1958) May 5.

The electrical conductivity of alkali metal solutions in their molten halides has been measured by means of a synthetic sapphire conductance cell. The specific conductance increases with increasing metal concentration. The equivalent conductance of K,  $\Lambda_K$ , in both KCl and KBr also increases, namely, from 2800 ohm<sup>-1</sup> cm<sup>2</sup> (K-KCl, 820°), 6100 (K-KBr, 760°), and 6500 (K-KBr, 870°) at infinite dilution, to 38,000, 83,000 and 71,000 ohm<sup>-1</sup> cm<sup>2</sup> at 19, 23 and 20 mole % K, respectively, the maximum concentrations measured. However,  $\Lambda_{Na}$  for Na in NaBr at 895° decreases from 12,500 to a minimum of 7300 ohm<sup>-1</sup> cm<sup>2</sup> at ca. 9 mole % metal. At 805°  $\Lambda_{Na}$  in NaBr decreases from ca. 12,000 at infinite dilution, i.e., approximately the same value at 895°, to less than 5000, and in NaCl at both 845 and 890° from ca. 6000 to less than 3000 ohm<sup>-1</sup> cm<sup>2</sup>. These values are the equivalent conductances at 5, 4 and 3 mole % Na, respectively, representing the metal solubility limits which are too low to permit the equivalent conductance minima to be realized. The different behavior of sodium and potassium may be related to the liquid phase equilibria and to the dissociation energies known for the diatomic gaseous metal molecules, both of which reflect a greater tendency to associate for Na than for K at the test temperatures. Such association, which increases with metal concentration, decreases the number of metal particles per equivalent of metal on which the electronic fraction of the conductance is thought to depend. The effect of the .....

- 3.140 Atomic Energy Research Establishment, Harwell, England  
Asher, R. C. et al.  
Lamellar Compound of Sodium with Graphite  
Nature 181, 409-10 (1958)

A lamellar compound of Na with graphite is prepared in a He atmosphere. Powdered graphite is heated, with continuous stirring, with about 3% Na at 120 to 500° for 0.25 hr. to 6 hrs. The product is virtually pure Na-graphite compound and resembles graphite but is deep violet. The main evidence for the formation of the compound is obtained by X-ray diffraction and analysis of the photographs suggests the formula C<sub>64</sub>Na. CA 52:10785

- 3.140 Thermodynamic Investigation of the System Mercury-Cadmium by the Circulation Method. Werner Meyer-Jungnick. Z.physik. Chem. (Frankfurt) 13, 184-201 (1957).

With a modified circulation app. that is illustrated and described in detail, vapor-liquid equil. were detd. on metallic mixed phases, on the system Hg-Cd in the temp. range 275-400°. The functions  $\Delta G^E$ ,  $\Delta H$ , and  $\Delta S^E$  (addnl, alteration of the molar enthalpy of mixt., of the chem. potential of mixt., and of the molar entropy of mixt., resp.) were calcd. from the data for an av. temp. of 360°. The results are listed and compared with data obtainable from literature. Comparison shows that the method is useful. CA 52:2485f

- 3.140 TID 3544  
PRODUCING A EUTECTIC POTASSIUM-SODIUM ALLOY. F. S. Maron and Z. P. Uspenskaya. Trudy Ural. Nauch. Issledovatel. Khim. Inst. No. 5, 91-8(1957). (Trans. from Referat. Zhur. Met. No. 8, 1958, p. 74).  
NSA 13:11222

- 3.140 Statistical Thermodynamics of Liquid Metallic Solutions by Shimoji, Mitsuo and Kichizo Niwa (Hokkaido Univ., Sapporo). Acta Met. 5, 496-501 (1957).

A cell model with a generalized potential field is applied to the liquid metallic solutions, since the interat. energy in liquid metal does not obey the inverse 6th power law. CA 51:16030

- 3.140 Liquid Metals and Solidification  
Sponsored by the ASM  
A Seminar on Liquid Metals and Solidification Held During the 39th National Metal Congress and Exposition, Chicago, Nov. 2 to 8, 1957.

The papers presented at this seminar include: The Theory and Structure of Liquids; Transport Properties in Pure Liquid Metals; Thermodynamics and Properties of Liquid Solutions; Nucleation in the Solidification of Metals; Solid Metal - Liquid Metal Reactions in Bi and Na; Discussion of Weeks and Gurinsky paper on Solid Metal - Liquid Metal Reactions in Bi and Na; Some Aspects of the Mechanism of Metal Deposition and Dissolution; Mechanism of Growth; Thermal Considerations of Freezing; Redistribution of Solute During Freezing; Imperfections Resulting from Solidification; Polyphase Solidification; and Structure of Ingots and Castings. (NSA 13:9065)

- 3.140 KAPL - 1763  
The Kinetics of Molten Metal-Water Reactions: A Report On Na<sub>2</sub>K-Water Vapor. H. M. Saltsburg. Apr. 30, 1957. 36 p.

A method has been suggested for the experimental study of the kinetics of the reaction of molten metals with vapors so that the reactive metal surface is relatively free from films of reaction product and the vapor flow is definable, not only in terms of pressure and composition, but also in a hydrodynamic sense. In this manner, the influence of vapor phase processes upon the heterogeneous reaction may be determined. Preliminary experiments are reported for NaK alloy (78% potassium) reacting with water vapor. Certain experimental difficulties are noted which make quantitative interpretation of the data not feasible at this time. Possible solutions are suggested.

- 3.140 CF-57-3-35  
Metal Hydrides Inc. Chemical Research Lab., Beverly, Mass. The Sodium Hydroxide-Sodium Oxide-Sodium-Sodium Hydride-Hydrogen System. Henry C. Kelly, Edward A. Sullivan, Sidney Johnson. Mar. 7, 1957. Decl. Apr. 1957 15p. (For Oak Ridge National Lab. Contract (W-7405-eng-26)).

Sodium hydride dissolves in and reacts with molten NaOH to give an equilibrium mixture of NaH, NaOH, Na<sub>2</sub>O, Na, and H. In the case where there is a gaseous phase (hydrogen) and only one condensed phase, the system is defined by the temperature, pressure, and one composition variable. The equilibrium H<sub>2</sub> pressure, which is a measure of the H<sub>2</sub> activity within the melt, was determined as a function of the composition of the condensed phase(s) at 600, 700 and 800° for equilibrium mixtures with original compositions of 2.5 to 97.5, 5.0 to 95.0, 10.0 to 90.0, and 20.0 to 80.0 mole % NaH-NaOH. The equilibrium H<sub>2</sub> pressure - composition isotherms obtained by removing measured increments of H<sub>2</sub> were reproduced by reabsorbing H<sub>2</sub>. Results for the 5.0 mole % NaH mixture were duplicated by starting with an equivalent quantity of either Na in NaOH or Na<sub>2</sub>O in NaOH, and reacting with measured increments of H<sub>2</sub>. The system is discussed in relation to the interdependent reactions involved, the phase rule, the thermodynamics of certain reactions, and experimental techniques employed.

NSA 12:2214

3.140 SDR PROJECT QUARTERLY TECHNICAL PROGRESS REPORT FOR THE PERIOD  
AUGUST 1, 1957 THROUGH OCTOBER 31, 1957. Dec. 31, 1957. 52p.  
 NDA-084-3

Engineering design and experimental studies have been continued with the objective of demonstrating the feasibility of separating Na and D<sub>2</sub>O in the Sodium Deuterium Reactor (SDR). A Na leak detection system is outlined. Design work has been completed on the multiple failure test apparatus, in which both water and Na system failures can be simulated at the same time.

3.140 Alkali Metal Oxides and Peroxides by Cunningham, G. L. (to  
Horizons Inc.) U. S. 2,784,061, March 5, 1957.

Alkali oxides are produced from dil. amalgams in an evacuable still by an oxidation process. Na amalgam contained in a still was enriched to 10% Na content by addition of Na to avoid high melting solid phases. Temp. and pressure are held at 450° and 50 mm. of Hg. The still is fed from an electrolysis cell with 0.4% Na amalgam. Hg is distilled off continuously fed returned to the cell, and Na<sub>2</sub>O is removed by skimming. By alternating the interrupted flow of amalgam from the electrolysis cell and the return of Hg distillate to the cell, a continuous process is provided while avoiding elec. coupling between the cell and still. This process is suitable for production of oxides, peroxides, and superoxides of the alkalis.

CA 51:8400

3.140 AECU-3519  
 Los Alamos Scientific Lab., New Mexico  
The Partition of Oxygen Between Sodium and Tantalum Holley,  
 Charles E. Jr., July 2, 1957. 8p. Contract W-7405-eng-36.

3.140 Determining the Activity of Potassium in Potassium-Mercury and  
Potassium-Lead Alloys in the Liquid State. A. G. Morachevskii  
 (M. I. Kalinin Polytech. Inst. Leningrad). Zhur. Priklad. Khim.  
 30, 1239-43 (1957),

The e.m.f. of cells K (electrolyte contg. K) K-Hg(Pb) was measured in cells previously used by M. (loc. cit.). The electrolyte for the K-Hg (I) alloy was glass No. 23 (7.4% K<sub>2</sub>O) and that for K-Pb (II) alloy was glass ZS-8 (3.8% K<sub>2</sub>O), both of which were liquids at the exptl. temps. The amalgams were prep'd. and the expts. were made in an atm. of A. The activity a<sub>k</sub> of K in I at 380° at mole fractions N<sub>k</sub> below 0.5 agreed with those of Vierk and Hauffe (C. A. 45.3693d) at 325°. At higher concns. there was a pos. deviation from Raoult's law. A pos. deviation was also suggested by the results of Redder, et al (C. A. 27, 4514). The excess partial molar free energy

$\bar{\Delta}F_k^x = 4.576T \log(a_k/N_k)$  was calcd. The plot

$$\Delta F^x = (1 - N_k) \int_0^{N_k} \bar{\Delta}F_k^x dN_k / (1 - N_k)^2 \text{ vs. } N_k \text{ passed through a max. at } N_k$$

corresponding to the compn. of KH<sub>2</sub>. The existence of this congruent compd. was suggested by previous expts. <sup>8</sup>(C.A. 49, 1417a). The a<sub>k</sub> and

$\Delta F_K^x$  for II were calcd. from the e.m.f. at 575°. The  $\Delta F^x$  vs. N<sub>k</sub> curve passed through a max. corresponding to the compn. of KPb. There was no indication of a break in the soly. curve or of the presence of conjugated solns. suggested by Smith.

CA 52:1736f

Transport and Chemical Control in the Dissolution of MetalsIn Mercury. J. A. R. Bennett and J. B. Lewis. June 1957. 48p.

United Kingdom Atomic Energy Authority. Research Group.

Atomic Energy Research Establishment, Harwell, Berks, England

The dissolution rates of tin, lead, and zinc in mercury and of benzoic acid in water and aqueous sucrose were investigated under conditions which solid cylindrical specimens are held stationary and concentric cells containing the solvent are rotated about them at predetermined speeds. The results indicate that the dissolution of tin and lead in mercury is transport controlled. The mass transfer coefficient data for these and the benzoic acid systems were correlated by the expression

$$\frac{KL}{v} = 0.018 \frac{Lu}{v}^{0.6} \frac{v}{D}^{-0.5}$$

The zinc data do not fit correlation due to the influence of the mean chemical rate with an activation energy of the order of 10 kcal/mole. Qualitative results obtained with single and multi-crystalline specimens of zinc indicate that different crystal planes of the zinc lattice dissolve at different rates. Data were also obtained for the dissolution of benzoic acid in water and aqueous sucrose by use of the expression

$$\frac{KL}{v} = 0.135 \frac{Lu}{v}^{0.6} \frac{v}{D}^{-0.6}$$

NSA 14:5064

- 3.140 Capacity of the Electrical Double Layer Between Mercury and Aqueous Sodium Fluoride. II. Effect of Temperature and Concentration by Grahame, David C. Amherst Coll., Amherst, Mass. J. Am. Chem. Soc. 79, 2093-8(1957).

The differential capacity of the elec. double layer between Hg and aqueous solutions of NaF was measured at 5 temperatures and 4 concentrations. The results agree with the theory previously proposed, and provide clues to the anomalous behavior of the elec. double layer. A new theory is suggested according to which the rise in the capacity on the anodic side of the potential of the electrocapillary max. is attributed to electrostriction. The "hump" is attributed to the formation of a pseudo-cryst. semi-rigid layer through which anions pass only with difficulty but without activation energy. The solvent next to the metal never achieves a state of free rotation comparable to that which it enjoys in the bulk of the liquid, and this partially explains why the dielec. coefficient of the inner layer is so much lower than that of pure water. Abs. values of the min. differential capacity, and values of the surface charge d. at -1.205 v. are tabulated for 0, 25, 45, 65, and 85°.

CA 51:11822

- 3.140 Liquid Sodium Alloy by D. D. Doptoglon (to National Distillers & Chemical Corp.) U. S. 2,806,785, September 17, 1957.

The alloy consists essentially of K, Na, and Hg in an at. ratio respectively, of about 3:14:2. The melting point is about 0.3°. A specific composition contains Na 38.6, K 13.7, and Hg 47.7%. This alloy can be prepared as follows: (1) 11 g. K is added to 100 g. of a 40% Na amalgam, and the mixture is heated under toluene until soln. is effected; (3) the Na<sub>2</sub>K from (2) is dild. to p. 6 times its vol. by gradual dildn. with the liquid metal prepared in (1). The alloy is said to be useful as a source of Na for org. reactions.

CA 52:1910i

- 3.140 AECU-3385

Massachusetts Inst. of Tech., Cambridge. Dept. of Metallurgy

Activities in Liquid and Solid Binary Metal SystemsProgress Report on Research Program for Feb. 1, 1956 to Jan. 31, 1957. Elliott, John F. November 13, 1956 14 p. Contract

AT(30-1)-1888

The progress made in the selection of materials and in designing of equipment for making e.m.f. measurements of 600 to 1000°C on liquid and solid binary alloy systems under the subject contract is reported. General status of the program is reviewed briefly. NSA 11:3414

- 3.140 An Investigation of the Sodium-Potassium Equilibrium Diagram  
MacDonald, K. K. E. et al  
Can. J. Phys. 34, 389-94 (1956)

The phase diagram of the system Na-K was investigated by measurement of electrical resistance of Na-K alloys. An incongruent compound  $\text{Na}_2\text{K}$  with a peritectic temperature of  $280.5^\circ\text{K}$ , and a eutectic temperature of  $261^\circ\text{K}$  was observed. The eutectic occurred at 66.6 at % K. Solid solutions were formed with Na containing a maximum of 3% K at  $280^\circ\text{K}$ , and with K containing a maximum of 4.5% Na at  $260^\circ\text{K}$ .

- 3.140 NYO - 6330  
Application of Chemical Thermodynamics to the Study of Alloy Formation. Progress Report for January 1, 1956 to April 1, 1956.  
W. E. Wallace, R. S. Craig, C. A. Krier, W. Saba, and M. G. Zabetakis. 7 p.

Provisional heat capacity results are available for Zn (12 to  $320^\circ\text{K}$ ) and Mg (20 to  $270^\circ\text{C}$ ). Final results for  $\text{Na}_2\text{K}$  (12 to  $321^\circ\text{K}$ ) are available and are being prepared for publication in the Journal of the American Chemical Society. Assuming the liquid alloys to be formed with  $\Delta S$  = the entropy of random mixing, the entropy of  $\text{Na}_2\text{K}$  at  $0^\circ\text{K}$  is 0.00 e.u./g. atom.  $C_p$  for  $\text{Na}_2\text{K}$  rises above the Dulong-Petit limit as its (incongruent) melting point is approached in a fashion rather similar to the rise in  $C_p$  for the pure alkali metals near their melting points.

- 3.140 Cohesive Energy of Potassium  
Berman, Sam et al  
Phys. Rev. 101, 1467-8 (1956)

The cellular method was applied to a calculation of the cohesive energy of metallic K. The crystal potential was taken from a self-consistent field with exchange for the K ion. An approximate exchange interaction between the valence and the core electrons was included. The cohesive energy was 18.5 or 19.3 cal./mole, depending on whether Pines' or Wigner's expression for the correlation energy was used. The effective mass was assumed to be 86% of the free-electron mass. The experimental value was 22.6 cal./mole.

- 3.140 Ionization on Platinum and Tungsten Surfaces, I. The Alkali Metals  
Datz, Shedon and Ellison H. Taylor  
J. Chem. Phys. 25, No. 3, 389-394 (1956).

The ionization of all of the alkali metals on tungsten and on tungsten oxide surfaces follows the Saha-Langmuir equation with no reflection. On platinum, however, a departure from this equation indicates partial reflection of the atoms. The reflection of Na is probably .0%, since the ionization efficiency is given closely by the Saha-Langmuir equation with a value of 5.50 ev for the work function of Pt at  $2000^\circ\text{K}$ . The same value of the work function then indicates reflections of 18% for Li, 48% for K, 22% for Rb, and 8% for Cs, at  $2000^\circ\text{K}$ .

- 3.140 TID 3544  
DETERMINATION OF THE MAXIMUM PRESSURES ATTAINED DURING THE REACTION OF SODIUM WITH AIR IN CLOSED SYSTEMS. Engineering Laboratory and Research Department Report 55C80. Edward Hines and J. K. Kelley. Feb. 15, 1956. 29p. (NP-7320)  
NSA 13:9372

- 3.140 TID 3544  
DETERMINATION OF THE MAXIMUM PRESSURES ATTAINED DURING THE REACTION OF SODIUM WITH AIR IN CLOSED SYSTEMS. Engineering Laboratory and Research Department Report P-55C80-a. Edward Hines and J. K. Kelley. Jan. 17, 1956. 10p. (NP-7524)  
NSA 13:13227

- 3.140 DEG-Memo-826, Some Properties of Thin Oxide Films on Sodium-Potassium Alloy Surfaces, Sutherland, D., Smith, A. W.  
(United Kingdom Atomic Energy Authority, Development and Engineering Group, Dounreay, Caithness, Scotland.

The reaction of oxygen at low concentrations in nitrogen with sodium-potassium alloy was investigated. It was found that a thin, almost insoluble, oxide coating forms on the alloy. The coating inhibits the absorption of oxygen at concentrations of 1 to 300 ppm.

- 3.140 Project OWL: 8-INCH WATER INJECTION TEST: RUN NUMBER 1. Preliminary Results. C. W. Sorenson, May 28, 1956. 7p. KAPL-M-SCT-10

Na heated to 600°F and flowing initially at 2980 gpm was subjected to water injection at the rate of 0.024 lb/sec. After about 124 sec the water injection was terminated because of greatly reduced Na flow. After ~ 10 min, a small leak was found in the loop at the point of water injection and the pressure in the loop was relieved by venting off gases. After the leak sealed itself, H<sub>2</sub> was removed by outgassing and the loop pressure raised to 20 psig by addition of N<sub>2</sub>. When the loop was heated to 653°F a few hours later, flow returned to normal. Cold trapping was successful initially at 500°F and eventually down to 300°F. A summary of flow, temperature, and pressure data are presented.

- 3.140 SODIUM-STEAM REACTION EXPERIMENTS. W. B. Woolen, D. Scott, and F. R. Dell. Oct. 1956. 19p. (AERE-CE/R-2158)

In view of the apparent complexity of the reaction between Na and steam, a large-scale experiment was devised as a climax to a number of early bench experiments, in order to simulate as closely as possible the effect of a small steam leak into Na in a Na/superheated steam heat exchanger. The reaction resulting from passing superheated steam through a 3/32-in.-diam hole into 44.8 lb of Na at temperatures of 450°C down to 282°C in the presence of Ar proceeded smoothly and inaudibly without any marked change of either temperature or pressure. Hydrogen was present in the gas and was given off as soon as the reaction commenced, but no O<sub>2</sub> or steam was detected. In a subsequent test dry Ar was passed through the same Na, and the presence of appreciable amounts of H<sub>2</sub> in the outgoing Ar indicated that NaH was present in the reaction products. Subsequent analysis of the contents of the reaction vessel at room temperature indicated that they were Na, NaOH, and NaH with less than 0.1% peroxide. There was no corrosion, by visual observation, of the 18/8/1 stainless steel nozzle or equipment.

- 3.140 Thermoelectric Properties of Metal-Ammonia Solutions. II. Thermoelectric Power of Sodium and Potassium Solutions at -78°, and the Effect of Added Salt on the Thermoelectric Power of Sodium at -33°.  
Lepoutre, Gerard and Jacob F. Dewald.  
J. Am. Chem. Soc. 78, 2953-5 (1956).

The thermoelectric power (d, microvolts/degree) of Na and K in NH<sub>3</sub> at -78° is less than previously reported values at -33°; this indicates a large positive temperature. A significant difference between Na and K values of  $\frac{\partial \mathcal{E}}{\partial T}$  is obtained at -78° in contrast to the behavior at -33°. An approximate logarithmic increase in the Thomson coefficient ( $\partial^2 \mathcal{E} / \partial T^2$ ) with dilution of metal is shown graphically. The addition of NaCl to Na in NH<sub>3</sub> at -33° causes anomalously large increases in  $\mathcal{E}$  and in the rate of increase of  $\mathcal{E}$  with dilution of Na; both effects increase with NaCl:Na ratio and are of the same mathematical form. III. Theory and Interpretation of Results. J. F. Dewald and Gerard Lepoutre. Ibid. 2956-62. Thermodynamic equations are derived for the thermoelectric properties of metal-NH<sub>3</sub> systems that include the effects of electron-electron and electron-ion interactions. The previously reported anomalies in the thermoelectric behavior of metal and metal-salt solutions. (loc. cit.) are shown not to arise from these interactions, but from a large negative heat of transport of electrons in these solutions. ( $Q_e \approx -0.7$  e.v.), and is accounted for on the assumption that the electrons move through solution by a quantum tunnel process rather than by ionic or conduction-band processes. The results are applied to the calculation of a value for the standard molar entropy by ammoniated electrons which disagrees with that of Latimer and Jolly.

3.140 Occurrence of Compound Molecules in the Vapor of Potassium  
Amalgam Melts, Roder, Alfred and Wilhelm Morawietz,  
Z. Elektrochem. 60, 431-54 (1956).

The composition of the vapor phase of K-Hg melts (I) was investigated by measurement of total pressure with a quartz spiral manometer, by analysis of the condensate in vacuum disn., and by molecular weight determination by the method of Volmer-Neumann-Bolker. At low temperature, the behavior of the vapor can be described in terms of the occurrence of molecules of  $\text{HgK}_3$ . Above  $250^\circ$  compounds of lower K content appear. True activities of the at. components calculated from mass-action constants agree with the results of e.m.f. measurements and obey the Duhem-Margules equation. Energies and entropies of mixing were calculated from the temperature coefficient of the activities. Vapor-pressure curves for K and for Hg were determined, and the heat of evaporation of the alloy system is reported as a function of composition. CA 50:16227

3.140 AECU-3289  
Illinois Inst. of Tech., Chicago. Armour Research Foundation  
The System Thorium-Mercury. Interim Summary Report No. 5 for  
April 1, 1955 to February 29, 1956. Domagala, R. F. and  
W. Rostoker. March 8, 1956. 27 p. Project No. B 076. for  
Oak Ridge National Lab. Contract W-7405-Eng.-26. Subcontract  
No. 765

A total of nineteen alloys was prepared by grinding Th chips into a pool of Hg contained in a Vycor bulb. This operation was conducted under a protective A atmosphere. The bulbs were sealed and given an anneal to promote the production of homogeneous alloys. These alloys were found to be reactive with air so that all operations requiring alloy transfers from their original container were conducted in a "dry-box". Alloys up to 18.5% Th were subjected to thermal analysis and resistivity studies to position a peritectic reaction at  $-32^\circ\text{C}$  and a very steeply rising liquidus in the Hg rich region of the system. X-ray and chemical analysis studies of as-prepared alloys as well as alloy specimens treated in "U" tube experiments provided for the identification of a hexagonal  $\text{ThHg}_3$  phase and two face centered cubic phases, tentatively  $\text{ThHg}$  and  $\text{Th}_3\text{Hg}$ . While a complete diagram cannot be constructed at this time, only a limited number of possible forms can be drawn and these are shown. It was also demonstrated that removal of Hg from the alloys even at temperatures as high as  $100^\circ\text{C}$  is not complete in short times and that very likely kinetics problems are involved in any discussion of the decomposition of phases in this system.

NSA 10:9307

3.140 AECU-3290  
Illinois Inst. of Tech., Chicago. Armour Research Foundation  
The System Thorium-Mercury. Progress Report No. 6 for March 1,  
1956 to April 30, 1956. Domagala, R. F. and W. Rostoker.  
May 14, 1956. 10 p. Project No. B 076. for Oak Ridge National  
Lab. Contract W-7405-Eng.-26. Subcontract No. 765

Phase relationships in the binary system Th-Hg are being studied. In addition a study of the increase in Th content of Hg-Th products by distillation as a function of time, temperature and initial mercury content is being pursued. Four large samples of an alloy containing 25% Th have been prepared and will be used for the beneficiation work. Several alloys for phase relationship study have been made and additional compositions are currently being prepared. All alloys will be made by grinding Th chips into a pool of Hg in a Vycor tube under a protective A atmosphere and flame sealing the bulb in vacuo when the proper composition is reached. Experimental work to resolve the problem of  $\text{ThO}_2$  patterns observed in X-ray films of certain alloys in earlier work is in progress. NSA 10:9308



- 3.140 AECU-3285  
Illinois Inst. of Tech., Chicago, Armour Research Foundation  
The System Thorium-Mercury. Progress Report No. 1 for April 1,  
1955 to June 1, 1955. Domagala, R. F. and W. Rostoker. June 13,  
1955. 11 p. Project No. B 076 for Oak Ridge National Laboratory.  
Contract W-7405-eng-26 Subcontract No. 765

Phase relationships in the Hg-Th system are to be determined. No alloys have as yet been prepared, although two approaches to this work are currently being pursued. In one method Th grindings will be introduced into a capsule of Hg, sealed, and "cooked". All steps including grinding are being conducted under vacuum or A. The second technique consists of passing Hg vapor over heated Th in a completely enclosed, recirculating system. By these alloying procedures it should be possible to determine phase relationships in this system by proceeding from each end of the diagram. Samples will be subjected to thermal and x-ray analysis to position the liquidus, solidus and any intermetallic compounds which exist. NSA 10:9303

- 3.140 AECU-3287  
Illinois Inst. of Tech., Chicago, Armour Research Foundation  
The System Thorium-Mercury. Progress Report No. 3 for Aug. 1,  
1955 to Sept. 30, 1955. Domagala, R. F. and W. Rostoker.  
Oct. 19, 1955. 11 p.  
Project No. B 076 for Oak Ridge National Lab.  
Contract W-7405-Eng-26. Subcontract No. 765

Mercury-thorium alloys containing from 0.7 to 72.9% Th were prepared by grinding Th chips into a bulb of Hg under a protective atmosphere. Thermal analysis of five of the alloys and pure Hg has shown a definite and reproducible use in the melting point of Hg with Th additions. A peritectic horizontal at  $-32^{\circ}\text{C}$  has been tentatively set at the Hg-rich region of the diagram. Information to date substantiates  $\text{ThHg}_3$  as being the first intermediate phase encountered in the system going from the Hg end. The Hg vapor-heated Th apparatus has been demonstrated to be of no value for preparing Th-rich alloys. NSA 10:9305

- 3.140 AECU-3288  
Illinois Inst. of Tech., Chicago. Armour Research Foundation  
The System Thorium-Mercury. Progress Report No. 4, for Oct. 1, 1955  
to November 30, 1955. Domagala, R. F. and W. Rostoker. Dec. 19,  
1955. 12 p. Project No. B-076 for Oak Ridge National Lab.  
Contract W-7405-Eng-26 Subcontract No. 765.

Alloy specimens were prepared over the composition range 0.7 to 79.2% Th. A technique of dropping freshly cut chips into a pool of Hg under protective atmosphere conditions was selected as the best method of alloying. Transfers of these reactive alloys to X-ray capillary and other tubes were successfully accomplished in a "dry-box" constructed for this purpose. X-ray photograms have established the existence of a hexagonal intermediate phase with the parameters  $c = 4.911 \text{ \AA}$  and  $a = 3.367 \text{ \AA}$ . Resistivity experiments with Hg-rich alloys have shown a very sharp rise in the liquidus temperature with increasing amounts of Th. NSA 10:9306

- 3.140 KAPL-M-JRG-2  
Knolls Atomic Power Lab., Schenectady, N. Y.  
Removal of Mercury from SIR Coolant (E-3 Experiments)  
Gould, John R. and J. G. Gratton. October 17, 1955. 5p.  
Contract W-31-109-Eng-52

The removal of Hg from Na (SIR coolant) by precipitation as a Ca-Hg compound was studied. No evidence of a Ca-Hg reaction was observed over a period of 10 hours at  $700^{\circ}\text{K}$ ; however, the reaction goes to completion within 1/2 hour at  $870^{\circ}\text{K}$ . The solubility of  $\text{Hg}_{\text{x}}\text{Ca}_{\text{y}}$  in a Na solution is approximately 0.1 to 0.3 wt % at  $870^{\circ}\text{K}$ .

NSA 10:10768

- 3.140 KAPL-M-GJB-2  
Knolls Atomic Power Laboratory, Schenectady, N. Y.  
Sodium Flush Program by Barenborg, G. J. dated Nov. 12, 1954. 10p.  
Contract W-31-109-Eng-52.

A research program for development of a sodium flush procedure for the SIR is described. The purpose of the procedure would be to allow early access to the lower reactor compartment following operation.

NSA 11:13156

- 3.140 CLEANING ALKALI METAL SYSTEMS WITH LIQUID  $\text{NH}_3$ : Memo 59. W. Milich and E. C. King. June 1954. Dec1. Aug 2, 1955. 8p. (NP-6429)

Results of two cleaning operations indicate that liquid  $\text{NH}_3$  and  $\text{NH}_3\text{-NH}_4\text{Cl}$  washes are an effective method of removing Na and Na sludges from a liquid metal system.

- 3.140 Vacancies in Univalent Metals, Fumi, F. G. (Univ. of Cambridge, Engl.) Phil. Mag. 46, 1007-20 (1955).

A simplified calculation of the energy required to form a vacancy is given and applied to the noble and alkali metals. The metal is represented as a large spherical box in which the pos. charge of the ions is uniformly distributed and the electrons are free to move. When an ion is removed from the center of the sphere and spread over its surface, the energy of the free electrons changes because the electron waves undergo phase shifts in order to screen the vacancy and the volume of the metal box changes. The change in energy is proportional to the Fermi energy of the metal. For the noble metals another relevant contribution to the energy needed to create a vacancy is that of the closed-shell repulsion between ions: for Cu this is about -0.3 e.v. The energy to move a vacancy is also discussed; the electronic contribution is fairly small, and in noble metals the term due to the closed-shell repulsion predominates. This is probably somewhat underestimated. If there are used repulsive potentials valid in the neighborhood of the equil. interat. distance. The general agreement between the theoretical results and the experimental values for the energies to form and to move a thermal defect in the alkali and noble metals is satisfactory and suggests that vacancies are responsible for the transport of matter also in the alkali metals. CA 51:5536

- 3.140 Reaction of Carboniferous Materials with Sodium at High Temperatures  
Belyaev, A. I. and L. A. Firsanova  
Sbornik Nauch. Trudov. Moskov. Inst. Tsvetnykh Metal. i.  
Zolota 1955, No. 25, 162-71; Referat. Zhur., Met. 1956, No. 1110.

Results of investigation of reaction of Na vapors with various carboniferous materials (I) in vacuo at 400-1000° are presented. It is established that in all cases Na vapors are absorbed on I. On raising the temperature, the quantity of Na absorbed on I decreases. Destruction of I results from penetration of Na atoms in the interplanar spaces of the graphite lattice. Intensity of destruction increases not with the quantity of adsorbed Na but on the reduction of the degree of regularity of structure of I. i.e., removing it from 3-dimensional regularity, of the crystallization lattice of graphite, by degrees reducing the strength of the material on reaction with Na. Materials may be arranged in a series: graphite, thermoanthracite, metallurgical coke, petroleum coke, furnace coke. It is established that in the electrode industry flaky graphite more effectively raises the strength of material. The more resistant cathode blocks were those whose filler consisted of thermoanthracite coal dust (basically anthracite), and synthetic and natural graphite. (6-14%). CA 50:16074

3.140

NYO - 6320

APPLICATION OF CHEMICAL THERMODYNAMICS TO THE STUDY OF ALLOY FORMATION. PROGRESS REPORT FOR JANUARY 1, 1954 TO APRIL 1, 1954.

R. S. Craig, T. D. Brotherton, W. V. Johnston, S. Kamath, and C. A. Krier. Apr. 9, 1954. 8 p. Contract AT(30-1)647.

Calibration measurements have been completed on the equipment for measuring specific heats of potassium and  $\text{Na}_2\text{K}$  between 10 and 325°K. A sample of pure potassium has been prepared by triple distillation. Calibration measurements are in progress on the high-temperature adiabatic specific heat calorimeter (range 25 to 300°C). Equipment is being set up for a resistometric study of certain transitions in the magnesium-cadmium alloy system in the 200 to 300°K range. An X-ray diffraction camera has been modified for operation in this temperature range. (For preceding period see NYO-6165.)

3.140

RDB(C)/TN-33

Gt. Brit. Culcheth Lab., Culcheth, Lancs, England

The System; Sodium-Oxygen. A Review of Progress to March 1, 1953.

Oliver, D. S. and J. D. Noden. April 30, 1953. 13p.

The solubility of  $\text{O}_2$  in liquid Na is being investigated by a method previously employed by Williams. Samples prepared by filtration are analyzed by a method of amalgamation of the Na and flotation and estimation of the oxide. Insufficient results are as yet available to ascertain the complete shape of the liquidus in the  $\text{Na-O}_2$  system.

NSA 11:11060

3.140

DYNAMIC EFFECTS OF NaK-WATER REACTIONS IN THE GENIE SYSTEM.

O. R. Schurig. Mar. 19, 1951. Changed from OFFICIAL USE ONLY Oct. 3, 1956. 32p. (R51GL49)

3.140

NP - 1423

REACTION OF NaK AND  $\text{H}_2\text{O}$ ; TECHNICAL REPORT III. (N9onr-85801).

E. C. King and C. A. Wedge, Jr. Feb. 1, 1950. 49p.

Experimental data on the reaction of both superheated steam and liquid water with liquid sodium-potassium alloy of 66 wt % K composition is presented. A method is suggested for controlling the amount of damage that is possible in the reaction. A rough approximation is presented of the theoretical adiabatic and isothermal reactions of Na and  $\text{H}_2\text{O}$  assuming a completely filled and rigid container.

3.140

Heats of Formation of Sodium Potassium Alloy. Raleigh L.

McKisson, and LeRoy A. Bromley. Apr. 17, 1950. 10 p.

(UCRL-671). J. Am. Chem. Soc. 73, 314-15 (1951).

Measurements of the heat of formation of Na-K alloys were carried out by mixing liquid metals and noting the temperature drop. Values found for the heats of formation from the elements in their standard states are tabulated. All values are accurate to about 100 cal/mole.

3.140

SODIUM-RUBIDIUM ALLOYS. John R. Menke, Jan. 8, 1948. Decl. Dec. 21, 1955. 8p. Contract W-35-058-eng-71. (CNL-5). \$1.80(ph OTS); \$1.80 (mf OTS).

Attention is directed to the liquid-metal-alloy systems Na-Rb as coolants for reactors especially thermal reactors. The reported thermal neutron absorption cross sections of Rb are significantly lower than those for K. Physical constants are collected from the literature which indicate macroscopic physical properties similar to the Na-K alloys. Investigation of the ternary systems Na-Rb-K is suggested.

3.140

SODIUM-SODIUM HYDRIDE - HYDROGEN SYSTEM AT 500°-600°FBanus, D. M., et. a. J. Am. Chem. Soc., V. 77, 1955.

- 3.140 ANL-5115  
RESISTIVITY OF NaK  
 P. G. Drugas, I. M. Rehn, and W. D. Wilkenson  
 ANL, 1953.
- 3.140 ANL-5359  
EQUIPMENT AND PROCEDURES FOR STUDYING THE EQUILIBRIUM SOLUBILITY OF IRON IN NaK  
 P. G. Drugas, L. R. Kelman  
 Sept. 4, 1953.
- 3.140 AEC-tr-2906, The Electrical Conductivity and the Type of Bonding in the Alkali Carbides by Antropoff, A. von and J. Fr. Muller. Translated by F. Hudswell from Z. anorg. u. Allgem. Chem. 204, 305-14 (1932). 13 p.

Conductivity measurements with alternating current on  $\text{Na}_2\text{C}_2$  between 180 and 270° showed a behavior which is typical of ionic conductors. The values can be represented very well by the formula of Rasch and Hinrichsen and of Smekal. Experiments with direct current on  $\text{Na}_2\text{C}_2$  also showed phenomena typical of ionic conductors: formation of dendrites and polarization. By applying Tubandt's AgI method for the prevention of dendrite formation it could be established that transport of electricity in  $\text{Na}_2\text{C}_2$  is in accord with Faraday's law and is exclusively due to the  $\text{Na}^+$ . Mixtures of  $\text{Li}_2\text{C}_2$  and acetylide showed a behavior very similar to that of  $\text{Na}_2\text{C}_2$ , and thus  $\text{Li}_2\text{C}_2$  also must be regarded as an ionic conductor. The experiments confirm that the carbides of the alkali metals which we have studied are salt-like compounds.

NSA 11:6636

### 3.200 PURIFICATION OF LIQUID METALS

- 3.200 Alkali-Metal Purification  
 A. P. Litman, ORNL-3313, Annual Report, May 1962

Impurities, such as oxygen, nitrogen, and carbon, in alkali metals may cause alteration of the properties of container materials, affect mass transfer, or cause plugging due to precipitation of alkali-metal impurity compounds. Studies of methods for purifying the alkali metals have included low-temperature filtration, cold trapping, vacuum distillation, and gettering with active metals. Recent investigations by this group point to gettering, combined with low-temperature filtration in some cases, as the most practical and efficient method for lowering the oxygen content of the alkali metals. The gettering technique relies on the relative thermodynamic activity of the oxygen in the alkali metal vs that of the solid metal. The coefficient and the system kinetics are important factors in the purification process.

For purification, solubility, and corrosion studies, accurate analytical procedures are needed for several impurities. The lack of such procedures, especially for oxygen in the alkali metals, has seriously hampered progress in the areas of investigation mentioned above. For example, the correlation between the methods used in determining oxygen in potassium was poor, and when controlled oxygen additions were made, all the oxygen was not extracted from the potassium samples. A comprehensive review of existing analytical methods verifies the need for better techniques. An improvement may result from forthcoming modifications to the analytical equipment, revision of present sampling procedures, and advanced studies on a gettering vacuum-fusion method investigated a few years ago.

- 3.200 See Also: 1.400, 1.410, 1.620, 5.110 and 5.200.

The influence of alkali metal impurities such as oxygen, nitrogen, and carbon on corrosion phenomena in various alkali metal-container metal systems at elevated temperatures is discussed. The impurities may cause alteration of container metal properties, affect temperature gradient mass transfer, or, in cases of gross contamination, actually cause plugging due to precipitation of alkali metal-impurity compounds. Methods of reducing the concentration of these impurities include diffusion cold trapping, low temperature filtration, gettering with active metals at elevated temperatures, and vacuum distillation. Sampling techniques and analytical procedures for determining oxygen, nitrogen, and carbon in the alkali metals are reviewed briefly.

Materials Compatibility. Selection of container materials compatible with alkali metals at elevated temperatures has been a continuing research program for several years. One area that received attention during the past year was an evaluation of methods for removing impurities from alkali metals. The use of metals such as Zr and Ti as getters was found to be the most practical and effective means of reducing  $O_2$  content. Research was initiated to determine the distribution coefficient of  $O_2$  between potential getter materials and alkali metals.  $O_2$  contamination of alkali metal was observed to increase the corr. of many container materials. In evaluating the accuracy of the existing analytical techniques for determining  $O_2$  in the alkali metals, none of the analytical methods investigated gave satisfactory results. Therefore a program was initiated to develop a method for determining  $O_2$  content of K. An investigation of the effect of  $O_2$  concentration of refractory metals on their corr. resistance to Li at elevated temperature showed that the pure metals Nb, Ta, V, and Zr to exhibit excellent resistance at temperatures even in excess of  $800^\circ\text{C}$ . When small quantities of  $O_2$  were added to either Nb or Ta, Li penetrated these metals very rapidly over a wide range of temperatures. No attack was observed when V and Zr were contaminated with O to levels of 2000 and 4000 ppm, respectively.

NSA 16:30167

C is removed from molten coolants such as Na, Li, Sn and Bi by placing in the coolant stream thin sheets or ribbons of an element having a low C activity or strong affinity for C, such as Cr, Mn, Mo, Ta, Nb, Ti and V. The coolant is thus kept sufficiently free from C so that it does not carburize hot metallic structures that it cools. The getter element is more effective if used as an alloy with Fe or Ni in amounts between 5 and 10-30% by weight, for when pure, poor diffusion or compound formation interferes. Ternary and quaternary alloys are useful. If the getter is used in a hot trap, its temperature should be  $150-400^\circ\text{F}$  above the normal coolant temperature. Fe samples 0.06" thick containing 9 Cr, 1 Mo, & 0.1% C absorbed C up to 1.84% during 200 hours at  $1300^\circ\text{F}$  in Na saturated with C.

See 1.630, 1.600, 5.200, and 5.210.

Charles L. Gordon and Edward Wichers (Natl. Bur. of Standards, Washington, D. C.). Ann. N. Y. Acad. Sci. 65, 369-87(1957).

A review and compilation of data with 132 references. W. C. Tobie

CA51/11796i

- 3.211 IGR-174 (O/CA)  
ANALYTICAL METHOD FOR THE DETERMINATION OF SODIUM, LITHIUM AND POTASSIUM IN MERCURY.  
June 12, 1959. 9p. \$0.24(BIS).  
United Kingdom Atomic Energy Authority, Industrial Group.  
Capenhurst Works, Capenhurst, Ches., England

The mercury is shaken vigorously with dilute hydrochloric acid to extract the sodium, lithium, and potassium. The extract is then vaporized and burned in an atomizer-burner attached to a spectrophotometer. The method is applicable to the determination of sodium, potassium, and lithium in mercury containing from 2 to 50 mg/100 g of sodium, 5 to 50 mg/100g of potassium, and 5 to 50 mg/100g of lithium. Concentrations outside these ranges can be determined by suitable adjustment of sample aliquot. (auth)

NSA 13:20888

- 3.212 See Also: 1.600, 1.630, 5.210, 6.500.

- 3.212 RECOMMENDED LABORATORY PROCEDURE FOR THE PURIFICATION OF RECOVERED MERCURY  
IGR-176(O/CA) United Kingdom Atomic Energy Authority  
Industrial Group. Capenhurst, Ches., England, June 12, 1959  
7 p. \$0.21 (BIS)

Impurities are oxidized by prolonged compressed air blowing and removed by repeated water and nitric acid flushes.

NSA 13:19817

- 3.212 AD242563 (AF-CRL-99) A. D. Little Co., Cambridge, Mass.  
The Use of Organometallic Compounds in Purification of Mg, Ca, Hg, Ga, Ra and Ni by A. R. Gatti and A. G. Graham, 31 Dec. 1960.

Results of an experimental program devoted to the purif. of metals by the use of organometallic compounds are described.....Ultrapure Hg was prepared by decomposition of diethyl mercury with ultraviolet light..... High purity Re prepared from rhenium carbonyl by thermal decomposition .....

- 3.212 APPARATUS FOR THE TRIPLE DISTILLATION OF MERCURY  
M. J. Johcich, C. A. Alley, and M. Kowaka. J. Chem. Educ. 33, 607-8 (1956).

CA51-3169g

- 3.212 CF-56-1-151  
Oak Ridge National Lab., Tenn.  
The Hermex Process for Metal Decontamination by Mercury Processing by Morrison, B. H. and R. E. Blanco. Jan. 25, 1956. Decl. Feb. 14, 1957. 19p. Contract W-7405-eng-26.

The Hermex Process for the decontamination of irradiated metals and purifying scrap virgin metals is presented. The process as applied to irradiated U consists of the following steps: the irradiated U is continuously dissolved in boiling Hg at 365°C; the hot U-Hg solution from the dissolver vessel is withdrawn continuously leaving a slag layer containing ~ 87% of the fission products; the U-Hg solution is cooled to 25°C and concentrated by vacuum filtration; the U quasi-amalgam is washed with dilute HCl to remove the fission products; the Hg is volatilized from the quasi-amalgam; and the U melted to dense metal by slow heating to 1250°C in a single operation.

NSA 11:7506

- 3.212 IMPROVED METHOD FOR CLEANING MERCURY  
Fuschillo, N.  
Rev. Sci. Inst. 27, 410-11(1956).

A method is described which removes impurities such as zinc, lead and copper and alkali metals by means of atomization through a thin walled soft rubber hose. The fine droplets of mercury pass into a 10% nitric acid solution. Air rapidly sucked into the system through a cotton dustfilter creates a turbulence which improves the oxidation of the impurities. Details of construction and diagram of the apparatus are shown.

3.220 POTASSIUM (K)

3.220 WORK ON LIQUID METALS

C. F. Bonilla, Columbia University, N. Y.

Notes on Conference on Properties of Alkali Metals at BMI, April 1961

Thermodynamic properties of K.

3.220 Alkali-Metal Corrosion Studies

E. E. Hoffman, ORNL-3313, Annual Report, May 1962

The physical properties of alkali metals make them highly desirable as nuclear coolants and heat-transfer media. Unfortunately, the hazards associated with any leakage of these fluids as extensive use. In most cases, utilization has been limited to those systems in which no other heat-transfer fluid meets the requirements. For several years this group has been studying various facets of the corrosion problems inherent in containing flowing alkali metals at high temperature. During the past year, investigations were conducted on the optimum techniques for removing nonmetallic impurities and the development of suitable analytical procedures for determining the purity of alkali metals, on the relation between oxygen distribution and corrosion of refractory metals in contact with lithium, and on the use of a nickel-base alloy for containing boiling potassium.

3.221 To be expanded in the supplement. See 3.320.

3.222 DEG-Inf. Ser. 87 The Purification of K and Na.

C. Kunze (Translated by J. C. Ruckman UKAEA) from Vakuum-Tech., 8:168-70 (1959)

Procedures and equipment are described for purification of Na and K to spectrographic purity by vacuum distillation. The alkali metals must be pre-refined by passing over glass-wool and spheres prior to distillation, and care must be taken to prevent impurity uptake from glass apparatus by the metal.

NSA 16:4453

3.222 See Also: 3.232, 3.242, 5.220, and 6.500

3.230 SODIUM (Na)

3.230 THE CHEMISTS' CONTRIBUTION TO NUCLEAR ENERGY

Paulsen, F. R.. Nuclear Energy, 243-6 (June 1962)

The role of chemistry in the development of nuclear energy is discussed. Chemical studies described include: preparation of heavy water, removal of sodium oxide from liquid sodium, production of high-purity alkali metals, evaluation of zirconium behavior in contact with other materials, niobium extraction, chemical separation of radioactive materials, waste disposal, and fuel processing.

3.230 Purification of Sodium from Oxides and Methods of Oxide Content Control

Kirillov, P. L., Kozlov, F. A., Subbotin, V. I. and Turchin, N. M. Atomnaya Energ. 8, 30-6 (1960) January (in Russian) NSA 14:10412

Oxides in sodium coolants induce corrosion in the system and cause plugging. Data are given from tests made with cold traps for catching oxides. The data are useful in designing experimental and industrial installations using sodium and sodium-potassium coolants.

3.230 See Also: 1.620, 3.420, and 5.230.

- 3.230 SUMMARY OF NRL SODIUM PROGRAM  
J. P. Stone, Naval Research Laboratory, Wash. D. C.  
Notes on Conference on Properties of Alkali Metals at BNL, April 1961.  
Thermodynamic properties, (materials of containment include Cb-1Zr).

- 3.230 Inexpensive Way to Control Oxygen in Sodium Heat-Transfer Systems  
Gray, I. L. et al  
Nucleonics 14, No. 10, 34-34 (1956)  
Equipment is described for measuring and removing Na oxides from liquid Na and NaK when the latter is the heat-transfer media in nuclear power generation. A plugging indicator measures O<sub>2</sub> from 3-300 ppm. A stainless steel wire-mesh filter in a cold trap is used to reduce O<sub>2</sub> present as oxides to less than 10 ppm.

CA 50:16199

- 3.231 NDA-2154-6, Experimental Determination of Contaminants in Sodium,  
Steinmetz, H., B. Minuskin, (August 30, 1961)

An analytical method for the determination of oxygen in sodium was developed. The sodium was amalgamated with mercury and removed from the sodium oxide. The sodium oxide was then dissolved in an alcohol and finally reacted with an organic acid. The sodium oxide was thereby converted into an equivalent amount of water. This water was then titrated with Karl Fischer reagent. The method has the advantage of not requiring a complete separation of the sodium from the sodium oxide. The method was checked with samples containing known amounts of oxygen. The analysis of a series of samples of zirconium-gettered sodium gave a mean value of 3 ppm of oxygen with a standard deviation of 1.5 ppm. Three samples of sodium were analyzed for their carbon contents by a wet combustion method. The method used and the analytical results are described.

- 3.231 Control of Oxygen in Sodium Heat-Transfer Systems by Gray, I. L.  
et al. (General Electric Company, San Jose, Calif.)  
Chem. Eng. Progr. Symposium Ser. 53, No. 20, 11-18 (1957).  
CA 51:16010

- 3.231 SODIUM CONTAMINATING IMPURITIES IN HELIUM. H. A. Fremont, June 1, 1949.  
Decl. Mar. 9, 1957. 15p. (KAPL-M-HAF-1)

The following conclusions were reached from the considerations given: The important Na contaminating impurities in He are O, water vapor and hydrocarbons. The H and N content of the He used in a water moderated assembly (WMA) system should be limited to some moderate value. The present He purity specifications for WMA are not realistic and should be revised. Bimonthly repurification of the Na in the WMA reactor system should be considered. A proposed purity specification for the He to be used in the WMA reactor system is given, and is considered to be very conservative. A number of advantages to relaxing the existing He specifications are listed.

- 3.231 Purity Control in Sodium Cooled Reactor Systems  
Bruggeman, Warren H.  
AIChE J. 2, 153-6 (1956)

Recent advances in purity control in sodium systems are covered. Emphasis is placed on results from the prototype S.I.R. system as well as other unpublished data. Included are chemical and nuclear activation analyses of sodium, filtration data, and details and operation of cold traps and plugging indicators.

- 3.231 See Also: 3.330, 3.430.



- 3.231 CF-56-4-31  
Oak Ridge National Lab., Tenn.  
Procedure for the Determination of Oxygen in Sodium and NaK by  
the Distillation Method by White, J. C. April 5, 1956. 11p.  
Contract W-7405-eng-26.

The working procedure for the determination of oxygen in sodium and NaK by the distillation method is given. The apparatus, which is based on that developed by the Argonne National Laboratory, can be connected to either dynamic or static systems and makes possible the direct sampling of alkali at operating temperatures. Sodium and NaK have been sampled with this device at temperatures as high as 1400°F. The alkali metal is transferred, under pressure, to the sampler where a fixed volume of the metal is retained in a removable hemispherical cup. The metal is then distilled from the oxide at a temperature of 800°F and at a pressure of < 5 microns of Hg. After the sampler has cooled, the cup is removed from the sampler and the oxide, which remains as a residue in the cup, is dissolved in water. The resulting solution of alkali metal hydroxide is then titrated to a methyl orange indicator end point with a standard solution of hydrochloric acid. The concentration of oxygen in the alkali metal is calculated on the basis of the equivalents of acid consumed in the titration, and the weight of the alkali metal, retained during sampling, in the cup.

NSA 11:8290

- 3.231 KAPL-337  
Knolls Atomic Power Lab., Schenectady, N. Y.  
INVESTIGATION OF ALPLAUS ATMOSPHERIC PRESSURE SODIUM STILL.  
E. E. Baldwin. July 6, 1950. Decl. Nov. 22, 1955. 30p.  
Contract W-31-109-Eng-52.

As a result of two fires in the sodium still, an extensive investigation was made to determine the type and extent of damage and their cause. Results indicate that the external erosion and pitting was caused by action of the products of combustion of the Na fires, the argon line plug was due to localized oxygen contamination of the Na, and the internal surface damages were negligible.

NSA 10-3198

- 3.231 ON THE THERMAL BEHAVIOR OF SODIUM COMPOUNDS ESPECIALLY OF Na<sub>2</sub>O  
AND Na<sub>2</sub>S, AND THEIR REACTIONS WITH METALS.  
E. G. Buryel, and E. J. Kahlmeyer. Z. Anorg. U. Allgem.  
Chem. 254(1), (1947)

- 3.232 Experimental Investigations of the Removal of Sodium Oxide from  
Liquid Sodium  
Billuris, G.  
General Electric Company, Atomic Power Equipment  
Dept., San Jose, Calif.  
GEAP-3328, January 18, 1960, 57p. Contract N8-S-452  
for Atomics International, Div. of North American Aviation, Inc.

Information was obtained on the growth and characteristics of sodium oxide deposits in liquid sodium which could lead to system plugging, and the removal of sodium oxide from molten sodium by the cold trap method was studied. The data confirmed that the deposits are formed more rapidly with an increased amount of oxygen in the sodium, cooling of the deposit area, and fluid agitation. In general, the deposits at 300 F appeared to be silver in color with patches of liquid adhering to irregular crystalline-like structures. At room temperature the deposits were relatively hard and brittle and broken pieces of the structure appeared porous. During operation of the purification loop the apparent rate of solution of sodium oxide in sodium appeared to be much slower than the rate of removal in the cold trap. The data from the cold trap deposit indicated that up to 20 vol. % sodium monoxide could be collected in the trap before significant flow restriction was apparent. The most effective packing material tested was knitted wire mesh. With any of the packings tested, and operating with a residence time of about 8 minutes or longer, the effluent sodium from the cold trap did not appear to be supersaturated with oxygen.

NSA 15:3957

- 3.232 DEG-Inf. Ser. 87 The Purification of K and Na.  
C. Kunze (Translated by J. C. Ruckman UKAEA) from Vakuum-Tech.,  
8:168-70 (1959)

Procedures and equipment are described for purification of Na and K to spectrographic purity by vacuum distillation. The alkali metals must be pre-refined by passing over glass-wool and spheres prior to distillation, and care must be taken to prevent impurity uptake from glass apparatus by the metal.

NSA 16:4453

- 3.232 NAA - SR-Memo-4802  
PROTOTYPE FREEZE TRAP TEST  
R. Cygan (A.I.) Dec. 29, 1959, 6 p. OTS

A performance evaluation was made of a prototype liquid cooled freeze trap with Na at 350 and 1000<sup>o</sup>F. (more on abstract) NSA 14:23755

- 3.232 Heat and Mass Transfer Analysis of Proposed Experimental Cold Trap System  
McDonald, J. S. and Porez, F.  
Atomics International Div., North American Aviation, Inc.  
Canoga Park, Calif.  
NAA-SR-Memo-4578, 29 October 1959, 28 p.  
NSA 14:6755

Studies were made to investigate the possibility of removing oxide impurities from Na-cooled reactor systems by cold trapping in conjunction with fill-drain tanks.

- 3.232 NAA-SR-3638  
Control of Oxygen Concentration in a Large Sodium System  
Hinze, R. B.  
Atomics International Div., North American Aviation, Inc.  
Canoga Park, Calif.  
1 December 1959, 45 p.  
Contract AT-11-1-GEN-8

Data on the performances of two types of cold traps in the 50,000 lb radioactive sodium system at the SRE are tabulated. The rates were determined when trap inlet oxygen concentrations were at 8 to 10 parts per million. Oxygen concentration was readily controlled to 8 ppm using a cold trap. Extraction of oxygen from sodium by zirconium at 1200 F (hot trapping) reduces the concentration below the limit of detection, i.e., oxide solubility saturation temperature below 225 F. The theoretical limit for the equilibrium oxygen concentration was calculated to be less than  $7 \times 10^{-6}$  ppm. The observed extraction rate of 0.009 lb oxygen/hr was one-half of the rate predicted from material behavior studies.

NSA-14:5071

- 3.232 Bruggeman, W. H. et al. (to U. S. Atomic Energy Commission)  
Method for Removing Sodium Oxide from Liquid Sodium  
U.S. Patent 2,815,277, December 3, 1957

A method is described for removing sodium oxide from a fluent stream of liquid sodium by cold trapping the sodium oxide. Apparatus utilizing this method is disclosed in U.S. Patent No. 2,745,552. Sodium will remain in a molten state at temperatures below that at which sodium oxide will crystallize out and form solid deposits, therefore, the contaminated stream of sodium is cooled to a temperature at which the solubility of sodium oxide in sodium is substantially decreased. Thereafter the stream of sodium is passed through a bed of stainless steel wool maintained at a temperature below that of the stream. The stream is kept in contact with the wool until the sodium oxide is removed by crystal growth on the wool, then the stream is reheated and returned to the system. This method is useful in purifying reactor coolants where the sodium oxide would otherwise deposit out on the walls and eventually plug the coolant tubes.

CA 52:3651h &  
NSA 12:6993

- 3.232 See Also: 3.242, 5.120, 5.230, and 6.500.

- 3.232 SINTERED METAL FILTERS FOR SODIUM COOLANT SYSTEMS  
J. S. McDonald (AI) June 27, 1958. 10p. OTS (NAA-SR-Memo-2830)

Equations which express the relations between the pressure drop, pore size, flow rate, and filter thickness for sodium flowing through sintered metal filters were derived.

NSA 14:19055

- 3.232 KAPL-612  
INTERIM REPORT ON COLD TRAP INVESTIGATIONS.  
B. G. Voorhees and W. H. Bruggeman. Oct. 1, 1951.  
Decl. Jan. 5, 1956. 36p. Contract W-31-109-eng-52.  
\$4.80(ph OTS); \$2.70(mf OTS).

Recent tests of cold trapping have demonstrated the feasibility of this method for the removal of sodium oxide from sodium in a circulating system. A summary of work to date is presented with a description of test equipment, test procedures, and test results. Operating theories are discussed, and a brief outline of future development work is included.

- 3.232 Removal of Entrained Gas From a Sodium System  
Barker, K. R. and J. W. Mausteller  
Mine Safety Appliances Company, Callery, Penna. Technical Report No. 50  
Contract NObs-65426. 14p. July 12, 1956.

An efficient method for removal of entrained gas in a Na system similar to the S2G primary coolant system is described. A study of the behavior of air-water mixtures in a glass loop showed how gas moved through the system and gave a better understanding of two-phase flow. Air could be held up at various points depending on the velocity: down-stream end of upper horizontal run at 0.25 fps, in the vertical downward leg at 0.25 to 0.50 fps, and at the bottom of the vertical downward run at 0.50 fps. Entrained gas in the Na system caused erratic flowmeter and pump performance and flow stoppage at low velocities. An expansion tank located above the loop will remove gas at any flow condition great enough to transport gas to the vent. If it is necessary to transport gas downward to the expansion tank a minimum velocity must be exceeded. This was found to be between 1.5 and 2.3 fps in a 1 in. line 6 ft long. Gas removal rate is a function of velocity in the expansion tank like, but is independent of the main loop velocity. Entrained gas can be removed if liquid velocities are kept above 2 ft/sec and a normal separator is used in a by-pass line.

- 3.232 Filter with Fractional Crystallization Means  
Bruggeman, W. H. and B. G. Voorhees (to U. S. Atomic Energy Commission)  
U. S. Patent No. 2,745,552, May 15, 1956.

A cold-trap-type filter has been used to remove Na<sub>2</sub>O crystals from a molten sodium heat exchanger system. Oxygen entering such a system through leaks will combine with Na to form Na<sub>2</sub>O which will deposit in cooler portions of the system and choke the flow. This filter installed in a by-pass will remove the Na<sub>2</sub>O and other solid impurities that may be present in the molten sodium. The by-passed stream is cooled to 400°, then to 350°F in the filter, at which temperature the crystals are formed and then forced through steel wool which collects and holds the crystals and other impurities. The Na is then reheated to system temperature utilizing the heat extracted in the cooling steps. The holdup time required for Na passage is 5 minutes and the capacity is 7500 lbs/hr. The cooling surfaces must be periodically cleaned of deposits and the steel wool renewed as needed.

- 3.232 NP-7415  
REMOVAL OF MERCURY FROM SODIUM  
Rodgers, S. J.

Memo Report 97. Nov. 22, 1955. 5p. Contract NObs-65426

Three methods of removal of mercury from sodium were studied: fractional crystallization, amalgamation with copper showed promise in small systems but proved impractical in larger systems; cold trapping was ineffective. Copper corrosion in 800°F sodium was increased by a factor of ~ 24 over corrosion in 600°F sodium.

NSA 13:11611

3.232 PURIFICATION OF SODIUM FROM OXIDES AND METHODS OF CONTROL OF OXIDE CONTENT

P. L. Kirillor, F. A. Kozlov, V. I. Subbotin, and N. M. Turchin  
Atomnaya Energiya. Vol. 8, No. 1, (January, 1960) pp. 30-36.  
Submitted April 1959.

3.232 KAPL-M-JRG-2

Knolls Atomic Power Lab., Schenectady, N. Y.  
Removal of Mercury from SIR Coolant (E-3 Experiments)  
Gould, John R. and J. G. Gratton. October 17, 1955. 5p.  
Contract W-31-109-Eng-52

The removal of Hg from Na (SIR coolant) by precipitation as a Ca-Hg compound was studied. No evidence of a Ca-Hg reaction was observed over a period of 10 hours at 700°K; however, the reaction goes to completion within 1/2 hour at 870°K. The solubility of  $Hg_xCa_y$  in a Na solution is approximately 0.1 to 0.3 wt % at 870°K.

NSA 10:10768

3.232 MIXING OF RESIDUAL SODIUM WITH A SODIUM FLUSH. Report 2. Memo Report 68. E. F. Batutis, J. K. Powledge, and J. W. Mausteller. Nov. 4, 1954. 8p. NP-7394 NSA 13:14232

3.232 TID-2502(De1)

ON THE REMOVAL OF  $Na_2O$  FROM Na BY DISTILLATION. Leo Brewer and John L. Margrave. p.233-4 of NUCLEAR SCIENCE AND TECHNOLOGY. (EXTRACTS FROM REACTOR SCIENCE AND TECHNOLOGY. VOL. 1, ISSUES 1 TO 3, APRIL-DECEMBER 1951. 2p. UCRL-1241(Rev.)  
\$41.40(ph). \$11.10(mf) OTS.TID 3544 NSA 12:17329

---

3.240 SODIUM-POTASSIUM ALLOYS (NaK)

See Also: 1.620, 3.230, and 5.230.

3.241 DEG-Memo-826, Some Properties of Thin Oxide Films on Sodium-Potassium Alloy Surfaces, Sutherland, D., Smith, A. W. (United Kingdom Atomic Energy Authority, Development and Engineering Group, Dounreay, Caithness, Scotland.

The reaction of oxygen at low concentrations in nitrogen with sodium-potassium alloy was investigated. It was found that a thin, almost insoluble, oxide coating forms on the alloy. The coating inhibits the absorption of oxygen at concentrations of 1 to 300 ppm.

3.241 CF-3748

Argonne National Lab., Lemont, Ill.  
Determination of Hydrogen in Sodium-Potassium Alloy  
Simpson, O. C. and E. G. Rauh  
Dec. 23, 1946. Dec1. Feb. 16, 1956. 13p. Contract W-31-109-eng-38

An analytical procedure for the determination of very low concentrations ( $\sim 0.1$  at %) of  $H_2$  in Na-K alloys is presented. The procedure consists of converting the  $H_2$  present into  $OH^-$  ions, equilibrating with  $D_2O$  of known concentration, and determining, mass spectrometrically, the dilution of  $D_2$  in the  $D_2O$  by  $H_2$ . NSA 11:2264

3.241 See Also: 3.340, 3.440, 5.120, and 5.240.

- 3.242 IGR-TN/W-597, Unclassified, United Kingdom Atomic Energy Authority. Industrial Group. Windscale Works, Sellafield, Cumb., England  
Corrosion of Niobium and Vanadium in NaK Circuits; An Interim Report of Work at R and D.B. Windscale up to June 15, 1957.  
Draycott, A., Aug. 1957. 18p.

The results of some preliminary experiments in the compatibility studies of niobium and of vanadium in NaK circuits are reported. With normal cold trapping, corrosion of both these materials in a NaK circuit under Fast Reactor conditions is extremely high but can be reduced by incorporating in the circuit, elements with greater affinity for oxygen than the subject metals. This may be achieved by elements that are soluble in the liquid metal and react preferentially with any sodium oxide present. or by insoluble elements that show preferential oxidation at elevated temperatures. Results with the use of magnesium and barium are reported in the first group, and with zirconium, by means of a hot trap, in the second group. Because of the greater ease of control, more consideration has been given to hot trapping, but preliminary cleaning by cold trapping is still imperative. Detailed recommendations are made of the method for effecting this cold-trapping hot-trapping technique in the operation and maintenance of the Fast Reactor Circuit. (auth) TID-1181 No. 14-15 1337-1510

- 3.242 CF-55-11-102  
CHEMICAL EXAMINATION OF COLD TRAP FROM INTERMEDIATE HEAT EXCHANGER TEST STAND NO. 1, J. C. White, Nov. 17, 1955. 4p.

The oxide remaining in the cold trap of the NaK system was analyzed and the results are given and discussed.

- 3.242 THE COMPATIBILITY OF BERYLLIUM WITH LIQUID SODIUM AND NaK IN DYNAMIC SYSTEMS  
Bett, F. L. and Draycott, A. (Australia) 16 p.  
A/CONF. 15/P/1091, Peaceful Uses of Atomic Energy, 1958

The mechanism of corrosion of beryllium in oxygen-bearing sodium and NaK is briefly discussed. Experiments are described which measure the rate of corrosion of beryllium in cold-trapped NaK. These corrosion rates are found to be excessive. As oxygen in the liquid metal is considered to be the cause of the corrosion, cold trapping is supplemented by hot trapping as a means of deoxidation of NaK in a second series of experiments. These experiments show that with a thorium hot-trap reduced corrosion of beryllium occurs compared with cold-trap conditions, but is still excessive. Calcium, however, when used in the hot-trap reduces beryllium corrosion to an acceptable level. At the levels required for successful hot-trapping calcium removes negligible quantities of nickel from stainless steel which can therefore be used as a container material. NSA 13:6787

- 3.242 A Skimming Process For Removal of Oxide From Surface of NaK Alloy. E. F. Inall, (Aust Mat'l U, Canberra) Brit. Chem. Eng. 6, 38607 (1961)

A method of skimming the film of oxide of NaK alloy from the surface of the liquid metal in a homopolar generator consists of pumping in from below the surface a cover gas, which rises in large bubbles to break the surface skin and causes waves which force the skin towards the skimming outlet. It then passes through a downward sloping pipe to a separating drum and through a steel-wool filter with 0.003" aperture.

CA 55:18519

- 3.242 See Also: 3.232, 3.440, 5.240, and 6.500.

### 3.300 CHEMICAL ANALYSIS OF LIQUID METALS (TECHNIQUES)

- 3.300 ORNL 3313 Metals and Ceramics Div. Annual Progress Report for Period Ending May 31, 1962. Part II Materials Properties

Materials Compatibility. Selection of container materials compatible with alkali metals at elevated temperatures has been a continuing research program for several years. One area that received attention during the past year was an evaluation of methods for removing impurities from alkali metals. The use of metals such as Zr and Ti as getters was found to be the most practical and effective means of reducing  $O_2$  content. Research was initiated to determine the distribution coefficient of  $O_2$  between potential getter materials and alkali metals.  $O_2$  contamination of alkali metal was observed to increase the corr. of many container materials. In evaluating the accuracy of the existing analytical techniques for determining  $O_2$  in the alkali metals, none of the analytical methods investigated gave satisfactory results. Therefore a program was initiated to develop a method for determining  $O_2$  content of K. An investigation of the effect of  $O_2$  concentration of refractory metals on their corr. resistance to Li at elevated temperature showed that the pure metals Nb, Ta, V, and Zr to exhibit excellent resistance at temperatures even in excess of 800°C. When small quantities of  $O_2$  were added to either Nb or Ta, Li penetrated these metals very rapidly over a wide range of temperatures. No attack was observed when V and Zr were contaminated with O to levels of 2000 and 4000 ppm, respectively.

NSA 16:30167

- 3.300 LIQUID METAL INVESTIGATIONS, J. W. Semmell, Jr. (GE-FPLD)  
(NASA-AEC Liquid-Metals Corrosion Meeting, Dec. 1961 at BNL)

Na and K in testing up to 1850°F for 1) heat transfer studies, 2) operation of a turbine with K vapor, 3) analysis of liquid metals, 4) development of materials for liquid metal containment, 5) the study of corrosion phenomena. Data included in report. TID-7626 (Part 1) (AGN Lib. 2-2786)

- 3.300 TID-7626 (Part 1)  
DEVELOPMENTS IN THE ANALYSIS OF OXYGEN IN ALKALI METAL

H. Kirtchik and G. Riechman (G.E. ARO)  
(NASA-AEC Liquid Metal Corrosion Meeting, Dec. 1961 at BMI)

In order to avoid false apparent oxide values due to the summation of total oxides, it was deemed necessary to develop a method of sampling. Efforts have been illustrated. (AGN Lib. 2-2786) NSA 16:16687

- 3.300 NASA-N62-11319  
Kirtschik, H; Riechmann, G.; Research on Analytical Methods for Oxygen in Liquid Alkali Metals, Quarterly Progress Report No. 1  
(G.E. Cincinnati, Ohio) 15 Dec. 1960-31 March 1961 on NASA Contract NASr-12. 3 April 1961, 21 pp. DM-61-100

- 3.300 Karlamov, V. T., "Preparation of Analytical Samples of Alkali Metals for Vacuum Extraction," Trudy Komissii Anal. Khim., Akad. Nauk SSSR, Inst. Geokhim. i Auak. Khim. 10, 117-21 (1960). CA 55:6250d

- 3.300 FLAME-PHOTOMETRIC METHODS IN METALLURGICAL ANALYSIS  
J. A. Dean (Univ. of Tenn.)  
Analyst 85, 621-9 (1960) Sept.

Applications of flame photometry to the analysis of metallurgical products are not so widespread as the utility of technique warrants. Included is the flame analysis of liquid metals.

NSA 15:163

- 3.300 See Also: 3.200, 5.200, and 7.400.

3.300 AN X-RAY STRUCTURE INVESTIGATION OF THE LIQUIDS OF SODIUM, POTASSIUM, AND SODIUM-POTASSIUM ALLOYS

B. R. Orton, G. I. Williams, and B. A. Shaw  
(Fulmer Research Inst., Ltd., Stoke Poges, Buck., Eng.)  
Acta Met. 8, 177-86 (1960) Mar. (In English.)

The X-ray structures of liquid Na, K, and NaK were investigated by an improved method.

NSA 14:20627

3.330 IMPROVEMENT OF SEVERAL ANALYTICAL METHODS USED IN THE NUCLEAR METAL INDUSTRY

Jacques Robin, (Centre de recherches d'Ugine, Lyon).  
Energie nucleaire 1, 72-6 (1959) May-June (In French) (tr.)

Several examples of analytical control related to the nuclear energy industry are given. Corrosion of steel by molten Na at high temperatures can be evaluated either by direct study of the steel (weight variation or metallography) or by analysis of the Na before, during, and after the test. The apparatus used for sampling the Na and its operation are described.

NSA 13:17874

3.330 ESTIMATION OF TRACES OF NICKEL IN SODIUM METAL

(AAEC/E-23), T. M. Florence. Feb. 1958. 6p. Atomic Energy Commission Research Establishment, Lucas Heights, New South Wales, Australia.

NSA 13:16738

3.330 DETERMINATION OF TRACES OF OXYGEN IN SODIUM METAL BY INFRARED SPECTROPHOTOMETRY. PART I.

H. J. DeBruin and L. E. Smythe, June 1958. 4p. (AAEC/E-22)  
Atomic Energy Commission Research Establishment, Lucas Heights, New South Wales.

NSA 13:18855

3.300 USE OF RADIOISOTOPES IN THE CHROMATOGRAPHIC SEPARATION OF MIXTURES OF ALKALI METALS AND RARE EARTH ELEMENTS. (AEC-tr-4497(p.228-37))

M. M. Senyavin. Trans. from Trudy Vsesoyvz. Nauch.-Tekh. Konf. po Primenen. Radioaktiv. i Stabil. Izotopov i Izlucheni v Narod. Khoz. i Nauke, Moscow, 1957 (1958). Izotopy i Izlucheniya v Khim, p. 186-92.

The alkali metals and rare earth elements were taken as examples. Data obtained agreed with those of X-Ray spectroscopy.

NSA 16:3332

3.300 Electron Diffraction Study of the Structure of Liquid Metals and Alloys, Bublik, A. I. and Buntar', A. G.

Kristallografiya 3, No. 1, 32-42 (1958).

The structure of liquid metals and alloys was investigated by electron diffraction. The preparation of unbacked liquid films with a thickness of  $10^{-5}$  to  $10^{-6}$  cm and the design of the combination specimen holder and heater are described. Liquid Bi, Al, Sn, In, Bi-Sn, Al-Sn, and Al-In were studied. The results show that liquid metals have the same short distance order as the crystalline state at the melting point. In the case of metals with dense packing, the coordination number decreases with increasing temperature, but in the case of loose packing the number increases. At high temperatures the distribution density in all liquid metals approaches a smooth curve. Thin films of the liquid alloys, at temperatures close to the crystallization temperature, consist of regions enriched with one of the components. The character of the packing in these uniform regions is very similar to the packing in the corresponding pure liquid metals.

NSA 13:16250

- 3.300 Sampling and Analysis for Impurities to Liquid Impurities to Liquid Sodium Systems, by J. R. Humpreys, Jr., Paper from "Liquid Metals Technology," Pt. 1. Chemical Engineering Progress Symposium Series, p. 7-10. (1957)

Vacuum distillation apparatus and technique devised for sampling liquid sodium in reactor coolant systems and analyzing for oxides and metallic impurities. Equipment can be modified and used for Hg, Cs, Rb, K, Cd, Zn, Mg, or Li. 13 references. Metals Review, page 54, March 1958 (also, CA 51:16199a)

- 3.300 X-Ray Study of the Alkali Metals at Low Temperatures  
Barrett, C. S.  
Acta Cryst. 9, 671-7 (1956).

Using a spectrometer having provision for cold-working and X-raying specimens in a high vacuum at low temperatures, B. found that Na partially transforms on cooling (below 36°K) or on deforming (below 51°K). to a close-packed hexagonal structure with stacking faults, having  $a = 3.767$ ,  $c = 6.154$  A.,  $c/a = 1.634$  at 5°K., this coexisting with body-centered cubic Na of  $a = 4.225$  A. The body-centered cubic form at 78°K. has  $a = 4.235$  A. Severe cold-working at 5°K transforms about half of the material to the hexagonal form; subsequent revision to cubic starts on heating to 60-75°K. and is completed at 100-110°K., or at lower temperatures, if there has been no cold-working. Reversion can be aided by cold-working at 45-100°K. High purity, severely deformed Na recrystallizes at 98°K. Patterns of Li that has been cooled can be interpreted similarly; they indicate a phase of close-packed hexagonal structure with parameters  $a = 3.111$ ,  $c = 5.093$  A.,  $c/a = 1.637$  (which differ from the earlier, tentative ones. This phase coexists with the body-centered cubic phase of  $a = 3/40$ ; A., at 78°K. Confirming the earlier work (loc. cit) hexagonal Li is converted to face-centered cubic by cold-working. K, Rb, and Cs retain their body-centered cubic structure after cooling and cold-working at 5°K., with  $a = 5.225$ , 5.585, and 6.045 A., resp., at 5°K. and with  $a = 5.247$ , 5.605 and 6.607 A at 78°K.

CA 50:15164

- 3.300 AEC-tr-2999  
On the Role of the Flame Temperature in Flame Photometric Analysis of the Alkali Metals by Pungor, E. et al. Translated from Mikrochim. Acta 7-8, 1247-63 (1956). 16p

Several disturbing phenomena encountered in the flame photometric analysis of alkali metals were studied theoretically and explained with respect to the processes in the flame. The effect on the emission of excitation, ionization, thermal dissociation, and other individual processes was cleared up to a considerable extent. Atomizing burners functioning in the immediate vicinity of the flame were recommended for flame photometric determinations, and also equipment provided with prisms or lattices, since such devices eliminate several disturbing colloid chemical parameters, which are difficult to survey. When the atomizing is done in connection with a deflector, the alcohol effect appears, namely, the form of the alcohol concentration-emission curve becomes dependent on the change in surface tension, although it results from the overlapping of several parameters. Likewise, in addition to the atomizing rate, the flame temperature plays the dominant role in the familiar calibration curves, with whose aid the most favorable combustion and atomizing mixtures are set up. Li and Na are only slightly ionized in the oxyhydrogen flame, so they do not interfere in the photometric determination of the alkali metals, and vice versa. In contrast, K, Ru, and Cs undergo considerable ionization in this flame, whereby the emission is increased through mutual repression of the ionization. By mixing N with the atomizing gas (oxygen), the flame temperature can be lowered by more than 1000° without change of the other parameters, and this averts the disturbance due to the ionization and so makes possible the analytical determination of the three latter elements. The effect of the flame temperature on the form of the calibration curves is especially striking in the case of Cs, whose calibration curve, because of temperature lowering, changes from an S-form into one having a saturation character. The anion influence is ascribed to the thermal dissociation of the sprayed salts or of those that form in the flame.

NSA 11:11931



- 3.300 M-4241 (Pt. III)  
Princeton Univ., N. J. Frick Chemical Lab.  
A METHOD FOR THE DETERMINATION OF TRACES OF METALS III.  
STUDIES OF THE DISTILLATION OF AMALGAMS.  
C. E. Bricker, N. H. Furman, and Bruce McDuffie. 1946  
Revised Oct. 1947. Decl. Dec. 5, 1955. 9p. \$1.80 (ph OTS);  
\$1.80 (mf OTS).

Successful recovery of milligram quantities of Cd, Co, Fe, Ni, Cu,  
and Zn from amalgams was achieved by distillation in a N<sub>2</sub> atmosphere. (K.S.)

NSA 10-3493

---

3.310 MERCURY (Hg)

- 3.310 TID-16901  
SOME APPLICATIONS ON VACUUM DISTILLATION OF METALS TO RADIO  
CHEMICAL SEPERATIONS.  
J. R. DeVoe and W. W. Meinke (Univ. of Michigan, Ann Arbor)  
Anal. Chem., 35:2-6 (Jan. 1963)

The applicability of vacuum distillation of metals to radio-  
chemical seperations was explored using Hg, In, and Cd as examples.

NSA 17:6135.

- 3.310 DOSAGE DES VAPEURS DE MERCURE DANS L'AIR. APPLICATION A UNE  
SURVEILLANCE D'AMBIENCE.  
(The Dosage of Mercury Vapors in Air. Application to an Atmosphere  
Control)  
H. Francois, M. C. Vettier, and Y. Moser (France. Commissariat a  
l'Energie Atomique. Centre d'Etudes Nucleaires, Saclay) 1961.20p.

A technique was developed for trapping completely the Hg vapors  
in the atmosphere and analyzing them with precision. The analytical method  
used is particularly sensitive and makes possible the determination of 1  
microgram of Hg in a 1000 liter sample of air with an accuracy of  $\pm 2\%$ .  
The total time for the operation is about 2.5 hours, including the analysis.  
The operations are straightforward and can be carried out by specialized  
personnel after a short training period.

NSA 15:24805

- 3.310 IGR-174(O/CA)  
ANALYTICAL METHOD FOR THE DETERMINATION OF SODIUM, LITHIUM AND  
POTASSIUM IN MERCURY.  
June 12, 1959. 9p. \$0.24(BIS).  
United Kingdom Atomic Energy Authority, Industrial Group.  
Capenhurst Works, Capenhurst, Ches., England

The mercury is shaken vigorously with dilute hydrochloric acid to  
extract the sodium, lithium, and potassium. The extract is then vaporized  
and burned in an atomizer-burner attached to a spectrophotometer. The method  
is applicable to the determination of sodium, potassium, and lithium in  
mercury containing from 2 to 50 mg/100 g of sodium, 5 to 50 mg/100g of  
potassium, and 5 to 50 mg/100g of lithium. Concentrations outside these  
ranges can be determined by suitable adjustment of sample aliquot. (auth)

NSA 13:20888

- 3.310 AD 202 703, Div. 4  
THE DETERMINATION OF MERCURY AT ATMOSPHERE. ANALYTICAL METHOD  
United Kingdom Atomic Energy Authority  
1958, 7p. Report No. IGO-AM/CA-173

Notice all requests require approval of TIS, Oak Ridge, Tennessee  
TAB 15 August 1959:



3.320 POTASSIUM (K)

- 3.320 TID-7626 (Part 1)  
ALKALI METAL ANALYTICAL PROGRAM AT ORNL - DETERMINATION OF OXYGEN  
IN POTASSIUM  
J. C. White  
(NASA-AEC Liquid Metal Corrosion Meeting, Dec. 1961 at BNL)

Past work on Na, NaK. Present work on K has evolved a 7 minute analysis time by the use of scintillation spectrometry. AGN Lib 2-2786

- 3.320 THE SOLUBILITY OF ALKALI METALS IN ETHERS.  
J. L. Down, et. al., (Imperial Coll., London). J. Chem. Sci.  
3767-73 (1959) Dec.

K and NaK dissolve slightly (of the order of  $10^{-4}$  g-atom/l) in certain ethers to give unstable blue solutions which are considered to be similar to the well-known blue solutions of alkali metals in ammonia and amines. NSA 14:6224

- 3.320 Space Groups and Atomic Parameters in Some Graphite-Alkali Metal  
Lamellar Compounds  
Wolten, G. M.  
Atomics International Division, North American Aviation, Inc.  
Canoga Park, Calif.  
NAA-SR-4545, April 1, 1960 Contract AT-11-1-GEN-8

The crystallographic aspects of alkali metal-graphite lamellar compounds are reviewed, and space groups and atomic parameters are derived from some of them.  $\text{NaC}_{64}$ , and  $\text{RbC}_8$  crystallize in space group C222. If  $\text{NaC}_{64}$  is one of a series of sodium-graphite compounds, other members of the series would be expected to crystallize in the same space group. The remaining eight known potassium and rubidium compounds have a slightly different but similar structure. Experimental data for these are insufficient to permit a unique choice of space group. NSA 14:12530

- 3.320 Esnouf, M. P. (Univ. of Oxford)  
A Method for Determining  $\text{Na}^{24}$  and  $\text{K}^{42}$  when Present Together in Liquid  
Samples. Brit. J. Appl. Phys. 9, 161-2 (1958) April.

A simple method has been described for the separate determination of  $\text{Na}^{24}$  and  $\text{K}^{42}$  in liquid samples, which is based on the differential absorption of beta particles. The relative concentrations of the isotopes are estimated from the difference in the observed counting rates of a sample when it is measured in a type M6 tube and in a modified M6 tube. Details are given for the necessary modification of the M6 tube. NSA 12:8327

- 3.320 See Also: 3.220, 3.221, 5.220, and 7.420.
-

3.330 SODIUM (Na)

- 3.330 NAA SR 6986 A Device for Continuous Detection of H<sub>2</sub> in Na. H. Strahl (A.I. Div NAA), May 31, 1962  
Cont AT(11-1)-Gen 8

Device developed to detect as little as 1 ppm of H in Na (at 500-1200°F) and response time of 5 sec. NSA 16:20320

- 3.330 NAA-SR-5732, Detection Device for Hydrogen in Sodium  
Davis, K. A. (Jan 15, 1962)

A laboratory device capable of detecting trace amounts of hydrogen in liquid sodium has been developed. In loop operation the device extracts hydrogen from flowing sodium by allowing hydrogen diffusion through a nickel membrane. Ratio-of-rise measurements on a vacuum system placed on the exterior of the nickel barrier yields quantitative results. Spectrographic analysis of collected gas verifies the gas to be hydrogen. Sensitivity to detect 1.4 ppm (by weight) of hydrogen in sodium has been demonstrated. NSA 16:7686

- 3.330 TID-7626 (Part 1)  
DETERMINATION OF CARBON IN SODIUM-DEPOSITION OF REFRACTORY COATINGS FROM LIQUID METAL MEDIA-PROPERTIES OF MATERIALS EXPOSED TO 1200°F Na  
J. W. Mausteller and F. Tepper (MSA)  
(NASA-AEC Liquid Metal Corrosion Meeting, Dec. 1961 at BNL)

Analysis by Van Slyke oxidation - preparation of coatings that would resist liquid metal attack - Type 316 SS and 2-1/4 Cr-1Mo in two dynamic loops, test conditions recorded.

AGN Lib 2-2786

- 3.330 DEVELOPMENT OF A HIGH SENSITIVITY ANALYTICAL METHOD FOR OXYGEN IN SODIUM METAL  
Quarterly Progress Report for Oct 1, 1960 to Dec. 31, 1960.  
H. Steinmetz (Nuclear Development Corp. of America, White Plains, N. Y.)(NDA-2154-3) March 1, 1961. Contract AT(30-1)-2303 (XV) Scope 2. 12p.

The design of the apparatus was described in NDA-2154-2. All components operational. The gas handling system for preparing standard oxygen in Na samples was calibrated. Tests show that traces of zirconium or zirconium oxide do not interfere with the analytical procedure.

NSA 15:10835

- 3.330 TID-7626 (Part 1)  
EVALUATION OF EXISTING METHODS AND NEW PROPOSAL FOR THE DETERMINATION OF OXYGEN IN SODIUM.  
L. Newman (BNL)  
(NASA-AEC Liquid Metal Corrosion Meeting, Dec. 1961 at BNL)

Four general approaches utilizing photometric and spectrographic techniques.

AGN Lib 2-2786

- 3.330 TID-7626 (Part 1)  
FEASIBILITY STUDIES OF NON-CHEMICAL METHODS FOR DETERMINATION OF OXYGEN IN SODIUM AT LOW CONCENTRATIONS (BMI)  
(NASA-AEC Liquid Metal Corrosion Meeting, Dec. 1961 at BNL)

Inconclusive, but a format is set for subsequent evaluations in Report BMI-1538.

AGN Lib 2-2786

- 3.330 DETERMINATION OF TRACES OF OXYGEN IN SODIUM METAL BY INFRARED SPECTROPHOTOMETRY.  
H. J. DeBruin (Australian Atomic Energy Commission, Lucas Heights, New Smith Wales). Anal. Chem. 32, 360-2 (1960) Mar.

A method for the determination of traces of oxygen in Na metal by infrared spectrophotometry is presented. A method is suggested for handling of samples, contained in glass ampoules. NSA 14:8452

- 3.330 DETERMINATION OF MICROGRAM AMOUNTS OF COBALT IN SODIUM METAL. 2-NITROSO-1-NAPHTHOL SPECTROPHOTOMETRIC METHOD  
L. Silverman and R. L. Seitz. (AI). Anal. Chem. Acta. 20, 340-3 (1959) April

A colorimetric method is outlined for determining Co in Na metal..... NSA 13:12488

- 3.330 DETERMINATION OF TRACES OF OXYGEN IN METALLIC SODIUM  
J. Minczewski, D. Danciewicz, and S. Wasowicz (Inst. of Nuclear Research, Polish Academy of Science, Warsaw). Acta Chim. Acad. Sci. Hung., 33: 51-7 (1962) (In Russian)

The method is based on the formation of Na amalgam with Hg. NaO is insoluble in the resulting amalgam and floats on the surface. The amalgam is then completely removed by extraction with Hg. Amalgamation is performed in a special extractor in argon atmosphere which is previously purified by passing it through a NaK alloy. Samples of Na are stored in glass capsules. Following the extraction, NaO is dissolved in H<sub>2</sub>O, and O<sub>2</sub> is determined indirectly by flame photometry. Na is determined either by hydrolyzing the amalgamate followed by titration of excess acid and NaOH to a phenolphthalein end point or by flame photometry. This method was used to determine oxygen in amounts above 50 ppm. The standard deviation of several series of analysis did not exceed 13 ppm. NSA 17:7967

- 3.330 NAA-SR-1509 Experimental Techniques for the Determination of Oxygen in Sodium and in NaK by the Butyl Bromide Method  
Silverman, Louis and Mary Shideler  
Atomics International Div., North American Aviation, Inc., Canago Park, California Contract AT-11-1-GEN-8. June 16, 1956.

Modifications are suggested for the butyl bromide method for determining O<sub>2</sub> in Na. Tools for breaking the glass capsule and for cutting the Na are described. Chromatographic purification of the organic reagents by use of silica-gel was found to be effective and far more rapid than earlier purification methods. Data are included which show the effectiveness of this type of purification and which list the appropriate drying agents. Liquid NaK alloy can be handled by initially freezing the alloy and then controlling the speed of reaction by the temperature. After the K has reacted, the rate of Na reaction is accelerated by increasing the content of the butyl bromide.

- 3.330 Inexpensive Way to Control Oxygen in Sodium Heat-Transfer Systems  
Gray, I. L. et al  
Nucleonics 14, No. 10, 34-34 (1956)

Equipment is described for measuring and removing Na oxides from liquid Na and NaK when the latter is the heat-transfer media in nuclear power generation. A plugging indicator measures O<sub>2</sub> from 3-300 ppm. A stainless steel wire-mesh filter in a cold trap is used to reduce O<sub>2</sub> present as oxides to less than 10 ppm.

CA 50:16199

- 3.330 IMPROVEMENTS IN OR RELATING TO APPARATUS FOR DETERMINING THE METAL OXIDE CONTENT OF AN ALKALI LIQUID METAL  
W. B. Hall and A. Draycott (To United Kingdom Atomic Energy Authority) British Patent 883,632. Dec 6, 1961

An apparatus is designed for determining the metal oxide content of an alkali metal in a heat transfer circuit. The method is briefly described in the abstract. A specific version of the apparatus is described for determining  $\text{Na}_2\text{O}$  in liquid Na.

NSA 16:2989

- 3.330 EXPERIMENTAL DETERMINATION OF CONTAMINANTS IN SODIUM (NDA-2154-6)  
H. Steinmetz and B. Minushkin (United Nuclear Corp. Development Div., White Plains, N. Y.) August 30, 1961. Contract AT(30-1)-2303. 39p.

An analytical method for the determination of oxygen in Na was developed. (A wet chemistry technique. More on the abstract)

NSA 15:29123

- 3.330 DETERMINATION OF OXYGEN IN SODIUM AT CONCENTRATIONS BELOW 10 PPM (BMI-1538)  
D. R. Grieser, et al., Aug 31, 1961. Contract W-7405-eng-92. 38p.

New approaches to the problem of oxygen detection in Na were evaluated. Includes plugging indicator, vacuum distillation, and electrical resistivity. (More on abstract).

NSA 15:29117

- 3.330 NDA-2154-3, Development of a High Sensitivity Analytical Method for Oxygen in Sodium Metal--Quarterly Progress Report for the Period 1 October to 31 December 1960. Steinmetz, H., (1 March 1961)

The experimental apparatus was completely assembled. The design of the apparatus was described in the previous quarterly report. All components were tested and found to be operating satisfactorily. The gas handling system for preparing standard oxygen in sodium samples was calibrated. In addition, the necessary reagents and solvents were prepared, purified, and standardized. Tests show that traces of zirconium or zirconium oxide do not interfere with the analytical procedure.

- 3.330 COLLECTED METHODS FOR ANALYSIS OF SODIUM METAL (GEAP-3273)  
H. E. Perrine, Oct 15, 1959 (For AI) Subcontract N8-S-452.

Methods for analyzing chemical impurities in sodium metal samples are presented. Chemical analysis was used to determine impurities in calcium, carbon, chromium, iron, lithium, nickel, oxygen, potassium, and zirconium. Spectrographic analysis was used to determine other impurities. Sodium samples obtained from experimental apparatus were analyzed by these methods.

NSA 15:8668

- 3.330 ANALYTICAL METHOD FOR THE DETERMINATION OF OXYGEN IN SODIUM (TID-7623 (p 161-7))  
G. Stern (United Nuclear Corp. Dev. Div., White Plains, N. Y.)

An analytical method being developed for measuring the low oxygen content produced in Na from hot traps is described. . . . the method will be capable of measuring in the 1 to 10 ppm range for oxygen.

NSA 16:28560

- 3.330 Gasometric and Gravimetric Methods for Determining O<sub>2</sub> Content of Na and their Applications for Analysis of Oxide Content of Traps (In Russian) NSA 16:1882
- 3.330 SPECTROPHOTOMETRIC DETERMINATION OF COBALT IN SODIUM METAL.  
Louis Silverman and Rachel L. Seitz. NAA-SR-4005 Atomics International Div., North American Aviation, Inc., Canoga Park, California.  
 Oct. 15, 1959. 14 p. Contract AT-11-1-GEN-8. OTS

A colorimetric method, using 2-nitroso-1-naphthol is outlined for determining cobalt in sodium metal, which is used as a coolant in nuclear reactors. The sodium metal is reacted with water, neutralized with hydrochloric acid, and the cobalt content determined; the cobalt nitrosonaphtholate is extracted with carbon tetrachloride and the absorbance is measured at 535 m/μ. Chloride is requisite for the extraction of the cobalt complex in dilute solutions. Lithium and potassium, as well as sodium, have no effect. Ammonium ions have an adverse effect. As little as 0.1 ppm cobalt can be determined in sodium metal. In order to determine cobalt in the fractional ppm range, 10 gm of sample are used. The molar extinction coefficient is 11,780. (auth)

NSA 14-1-171

- 3.330 Sampling and Analysis for Impurities to Liquid Sodium Systems, by J.R. Humpreys, Jr., Paper from "Liquid Metals Technology," Pt. I. Chemical Engineering Progress Symposium Series, p. 7-10.

Vacuum distillation apparatus and technique devised for sampling liquid sodium in reactor coolant systems and analyzing for oxides and metallic impurities. Equipment can be modified and used for Hg, Cs, Rb, K, Cd, Zn, Mg or Li. 13 references.

Metals Review, page 54, March 1958

- 3.330 NAA-SR-Memo-2061, The Determination of Oxygen in Sodium--A Critical Review of Analytical Methods, Smith, C. R. F.,

Seven means of measuring the sodium monoxide content of liquid sodium are reviewed. Data relating to the solubility of sodium monoxide in sodium are collected. Methods and data are criticized from the standpoint of precision and systematic interferences. It is concluded that there is no proved method which is free from systematic interferences and which is capable of measuring oxygen in sodium in quantities of 400 ppm or less. It is recommended that a program be undertaken to make comparative tests of all analytical methods and to determine the solubility of Na<sub>2</sub>O in Na from 10 to 2000 ppm oxygen.

- 3.330 Determination of Oxygen in Sodium. The Mercury Method: Its Use in the Case of Very Low Concentrations  
 Champeix, L., Darras, R., and Duflo, J.  
 Centre etudes nucleaires Saclay, Gif-sur-Yvette, France  
 J. Nuclear Materials 1, 113-19 (1959) (in French)  
 cf. CA 53:21369d

The applicability of microanal, techniques to the classical Hg method of O detn. in Na (cf. Williams and Miller, CA 46:3330c; Pepkowitz, et al. CA 48:5022f) was examined with a modified app. operating under vacuum. The NaOH formed was detd. by flame spectroscopy.

CA 54:5335c

- 3.330 Esnouf, M. P. (Univ. of Oxford)  
A Method for Determining  $\text{Na}^{24}$  and  $\text{K}^{42}$  when Present Together in Liquid Samples. Brit. J. Appl. Phys. 9, 161-2 (1958) April.

A simple method has been described for the separate determination of  $\text{Na}^{24}$  and  $\text{K}^{42}$  in liquid samples, which is based on the differential absorption of beta particles. The relative concentrations of the isotopes are estimated from the difference in the observed counting rates of a sample when it is measured in a type M6 tube and in a modified M6 tube. Details are given for the necessary modification of the M6 tube.

NSA 12:8327

- 3.330 Determination of Sodium Oxide in Sodium, The Mercury Method: Its Utilization in the Case of Very Low Concentrations  
Champeix, L., Derras, R., and Duflo, J.  
Commissariat a l'Energie Atomique, Paris, France  
CEA-835, 1958, 10p

The precision of the mercury method for the determination of sodium oxide is evaluated for microanalytic applications. The apparatus used for the analysis, the procedure, and the calibration are described in detail. Flame spectroscopy was used for the determination of the sodium hydroxide formed. The errors introduced by the presence of sodium and calcium chlorides are discussed. The results obtained are examined with respect to their reproducibility. The method can be used for the determination of oxygen in sodium at values less than 10 ppm with satisfactory precision if care is taken in the procedure.

NSA 13:17781

- 3.330 Measurement of Concentration of Tungsten Suspensions and Density of Liquid Sodium by Gamma Ray Absorption. J. S. Watt and K. R. Lawther, "Australian Atomic Energy Symposium, 1958"

Gamma ray absorption techniques were applied to measure the density of various media. In the case of liquid sodium contained in a stainless steel vessel, preliminary experiments indicate that the density may be measured to an accuracy of  $\pm 0.01$  gm/cc, and that 0.01 gm/cc transient changes in density occurring in a few seconds can be resolved.

NSA 14:1254

A colorimetric method is outlined for determining cobalt in sodium metal, as little as 0.1 ppm cobalt can be determined.

- 3.330 IGO-AM/CA-110  
United Kingdom Atomic Energy Authority. Industrial Group. Capenhurst Works, Capenhurst, Ches., England  
The Analysis of Sodium Metal and Sodium-Potassium Alloy (collected Capenhurst Methods). March 1958. 59 pages

Various methods for the sampling of sodium or sodium-potassium alloys from storage drums or similar containers are outlined. A sample is withdrawn from the bulk storage container by means of a suction pump. The whole operation is carried out under an atmosphere of nitrogen. Associated apparatus and experimental procedures are included.

NSA 12:10388

- 3.330 See Also: 3.230, 3.231, 5.230, and 7.420.



3.340 SODIUM-POTASSIUM ALLOYS (NaK)

3.340 QUALITATIVE TEST OF THE INERTNESS OF GAS TO COVER SODIUM - POTASSIUM ALLOYS

E. K. Inall (Australian National Univ. Canberra)  
Rev. Sci. Instru., 32:1257-8 (Nov 1961)

A sampling device, which consists of a glass envelope enclosing a glass bowl, was designed for cleaning NaK surfaces. The surface in the bowl can be cleaned by passing a 20 amp current between two electrodes, so that NaK is pumped up through the tube into the bowl. This produces a clean surface on the NaK in the bowl, if the gas is free of reactive contaminants, or if the gas has been pumped out, leaving a pressure of less than 1 mm Hg, so that the remaining contamination is rapidly removed by reaction with the NaK.

NSA 16:13345

3.340 Determination of the Solubility of Oxygen-Bearing Impurities in Sodium, Potassium, and Their Alloys

Williams, D. D., et al  
Naval Research Lab, Washington, D. C.  
J. Phys. Chem. 63, 68-71 (1959); cf. C. A. 51, 10195c

The compds. resulting from partial oxidation of K and Na metal were isolated and identified as the respective monoxides. The equil. oxide in a Na-K-O system was  $\text{Na}_2\text{O}$ . The solubilities in the following systems were detd. as a function of temp:  $\text{Na}_2\text{O}$  in Na, K, and Na-K alloys;  $\text{K}_2\text{O}$  in K, NaOH in Na, mixed NaOH- $\text{Na}_2\text{O}$  in Na, and  $\text{Na}_2\text{CO}_3$  in Na. Pos. errors in oxide content may result from failure to account for each species of impurity if sepn. and analysis of a sample depends solely upon total alk. calcn.

CA 53:7855b

3.340 Determination of Hydrogen in Alkali Metals by Isotope Dilution Method

Holt, Ben D., Argonne National Laboratory, Lemont, Ill.  
Anal. Chem. 31, 51-4 (1959) Jan. 4468

The rapid exchange of hydrogen and deuterium in sodium or NaK affords a convenient method for hydrogen determination in these metals. Spikes equivalent to 5 to 250 ppm of hydrogen were recovered on 2-gram samples with a standard deviation, from the quality added, equivalent to  $\pm 2$  ppm. An 8-in. borosilicate sampling tube serves as the reaction vessel and as the gas bulb for mass spectrometric analysis. With many such tubes on hand, samples can be taken at sites of industrial operations and transported in the laboratory for analysis. In the analysis of NaK it is necessary to apply a correction factor to compensate for the effect of different rates of formation of the hydrides and deuterides in the cooler zones of the tube during equilibrium. For sodium this effect is negligible and no correction is necessary. The time required for analysis after the sample is taken is about 3/4 hour.

NSA 13:4468

3.340 United Kingdom Atomic Energy Authority  
Analysis of Sodium Metal and Sodium-Potassium Alloy, 1958; 65p.  
Metals Review, December 1958, page 83

- 3.340 THE SOLUBILITY OF ALKALI METALS IN ETHERS.  
J. L. Down, et. al., (Imperial Coll., London). J. Chem. Sci.  
3767-73 (1959) Dec.

K and NaK dissolve slightly (of the order of  $10^{-4}$  g-atom/l) in certain ethers to give unstable blue solutions which are considered to be similar to the well-known blue solutions of alkali metals in ammonia and amines. NSA 14:6224

- 3.340 ORNL-2993  
HEAD-END AND SOLVENT EXTRACTION PROCESSING (p. 1-57)

Fuels bonded with Na or NaK cannot be processed by the Darex process. NSA 14:25542

- 3.340 THE DETERMINATION OF TRACE ELEMENTS IN METALLIC SODIUM AND SODIUM-POTASSIUM ALLOY BY THE POROUS CUP TECHNIQUE  
G. I. Goodfellow, et. al., 1959. Date of MS Aug. 31, 1954  
18 p. (ARDC/P-34). United Kingdom Atomic Energy Authority.  
Industrial Group. Springfields Works, Springfields, Lancs, England.

A method for the determination of trace amounts of 15 elements in metallic Na and NaK (22.7% Na - 77.3% K) was developed. The porous cup method of excitation is used with palladium as internal standard. The spectra are recorded by means of a spectrograph. Microphotometry and a plate calibration technique are used for the evaluation of the spectrograms so obtained. Detection limits range from 2 to 15 ppm in the alkali metal or alloy. NSA 14:9480

- 3.340 IGO-AM/CA-110  
United Kingdom Atomic Energy Authority. Industrial Group. Capenhurst Works, Capenhurst, Ches., England  
The Analysis of Sodium Metal and Sodium-Potassium Alloy (collected Capenhurst Methods). March 1958. 59 pages

Various methods for the sampling of sodium or sodium-potassium alloys from storage drums or similar containers are outlined. A sample is withdrawn from the bulk storage container by means of a suction pump. The whole operation is carried out under an atmosphere of nitrogen. Associated apparatus and experimental procedures are included. NSA 12:10388

- 3.340 CF-3748  
Argonne National Lab., Lemont, Ill.  
Determination of Hydrogen in Sodium-Potassium Alloy  
Simpson, O. C. and E. G. Rauh  
Dec. 23, 1946. Dec. 16, 1956. 13p. Contract W-31-109-eng-38

An analytical procedure for the determination of very low concentrations ( $\sim 0.1$  at %) of  $H_2$  in Na-K alloys is presented. The procedure consists of converting the  $H_2$  present into  $OH^-$  ions, equilibrating with  $D_2O$  of known concentration, and determining, mass spectrometrically, the dilution of  $D_2$  in the  $D_2O$  by  $H_2$ . NSA 11:2264

- 3.340 NAA-SR-1509 Experimental Techniques for the Determination of Oxygen in Sodium and in NaK by the Butyl Bromide Method  
Silverman, Louis and Mary Shideler  
Atomics International Div., North American Aviation, Inc.,  
Canago Park, California Contract AT-11-1-GEN-8. June 16, 1956.

Modifications are suggested for the butyl bromide method for determining  $O_2$  in Na. Tools for breaking the glass capsule and for cutting the Na are described. Chromatographic purification of the organic reagents by use of silica-gel was found to be effective and far more rapid than earlier purification methods. Data are included which show the effectiveness of this type of purification and which list the appropriate drying agents. Liquid NaK alloy can be handled by initially freezing the alloy and then controlling the speed of reaction by the temperature. After the K has reacted, the rate of Na reaction is accelerated by increasing the content of the butyl bromide.

PROCEDURE FOR THE DETERMINATION OF OXYGEN IN SODIUM AND NaK BY THE DISTILLATION METHOD. J. C. White, Apr. 5, 1956. 11p.  
(CF-56-4-31)

The working procedure for the determination of O in Na and NaK by the distillation method is given. The apparatus, which is based on that developed by the Argonne National Laboratory, can be connected to either the direct sampling of static systems and makes possible the direct sampling of alkali at operating temperatures. Na and NaK have been sampled with this device at temperatures as high as 1400°F. The alkali metal is transferred, under pressure, to the sampler where a fixed volume of the metal is retained in a removable hemispherical cup. The metal is then distilled from the oxide at a temperature of 800°F and at a pressure of <5 microns of Hg. After the sampler has cooled, the cup is removed from the sampler and the oxide, which remains as a residue in the cup, is dissolved in water. The resulting solution of alkali metal hydroxide is then titrated to a methyl orange indicator end point with a standard solution of HCl. The concentration of O in the alkali metal is calculated on the basis of the equivalents of acid consumed in the titration, and the weight of the alkali metal, retained during sampling, in the cup.

NSA 11:8290

- 3.340 REACTOR ENGINEERING AND SERVICES DIVISION. QUARTERLY REPORT (FOR) DECEMBER 1, 1950 THROUGH FEBRUARY 28, 1951. W. P. Bigler. Mar. 14, 1951. Dec1. Dec. 10, 1955. 29p. Contract W-31-109-eng-38.  
ANL-4596 \$4.80(ph OTS); \$2.70(mf OTS).

An electromagnetic pump, its head-capacity characteristics when pumping NaK, and its current supply are illustrated. The recommended building design for the Argonne Research Reactor is discussed. Heat transfer and fluid flow problems connected with D<sub>2</sub>O flow and the effect of the chilled water system on pile reactivity are discussed in some detail, as is pile control by water expulsion. Curves of heat production in U fuel rods after shutdown are given, measurements of the resonance integral of massive Th shapes are reported, and the status of an experiment on change in length of U metal under irradiation is summarized briefly.

- 3.340 NP-1527  
TECHNIQUE OF SAMPLING AND ANALYZING HOT FLOWING SODIUM-POTASSIUM ALLOYS (TECHNICAL REPORT IV). R. E. Lee and S. L. Walters.  
May 1, 1950. Dec1. Apr. 21, 1955. 17p.

Included are a method by which samples of 80% K and 20% Na are taken at temperatures from 90°F to 1100°F, a method involved taking a sample from a flowing stream in a metal bucket and transferring with entire contents to an analytical apparatus and analyzed for O content, and data indicative of the solubility curve for O in NaK.

- 3.340 See Also: 3.241, 5.240, and 7.420.

### 3.400 SOLUBILITY OF METALS AND OTHER ELEMENTS IN LIQUID METALS

- 3.400 FACTORS INFLUENCING THE SOLUBILITY OF SOLID METALS IN LIQUID METALS.  
J. R. Weeks, BNL. Presented at the 12<sup>th</sup> Annual AEC Corrosion Symposium, May 20-22, 1963, Castlewood, Pleasanton, California

Knowledge of the solubility of solid metal in a liquid metal, and of its temperature dependence, is essential to application of any theory of liquid metal corrosion.

At equilibrium, one can derive

$$\Delta H = T \left[ \Delta_{\text{fusion}} + \Delta S_{\text{excess}} - R \log (n) \right]$$

where  $H$  is the partial molal heat of solution of the solute atom and  $n$  is the mol fraction of solute in the saturated liquid. Thus a plot of  $\log (n)$  as a function of  $1/T$  is expected to yield a straight line, the slope and intercept of which yield respectively  $\Delta H$  and the excess entropy of solution.  $\Delta H$  represents the force of attraction between the solute and solvent metals.  $\Delta S_{\text{excess}}$  gives an indication of the association or order between solute and solvent atoms in the liquid solution. The relative values of  $\Delta S_{\text{excess}}$  for slightly-soluble solutes may be related to the relative vapor pressures of the solid metals. The presence in the liquid metal of trace impurities may override the basic solubility relationship in the clean system.

Data will be presented that lend support to each of the above conclusions.

- 3.400 AGN-8051  
RUBIDIUM CORROSION CAPSULE PROGRAM. QUARTERLY TECHNICAL REPORT.  
NOVEMBER 1, 1961 - JANUARY 1962, REPORT No. 4  
Arabian, Robert V.  
(Aerojet-General Nucleonics, San Ramon, Calif.)  
Contract AT(04-3)-368. 9p.

Tests are being carried out to obtain corrosion and solubility data on various containment materials for rubidium at temperatures from 1000 to 2000 F. Progress is reported on corrosion and solubility test runs, test analysis, and analytical procedures. (M.C.G.)

- 3.400 TID-7626 (Part 1)  
STUDIES ON SOME PHYSICO-CHEMICAL PROPERTIES OF LIQUID METALS  
AND DILUTE LIQUID METAL SOLUTIONS.  
S. W. Strauss, (NRL)  
NASA-AEC Liquid Metals Corrosion Meeting, Dec. 14-15, 1961  
Brookhaven National Laboratory, Upton, Long Island, N.Y.

An analysis of solubility, viscosity, surface tension, and density data taken from literature. Equations have been formulated for use in thermodynamic considerations. (AGN Lib. 2-2786)

- 3.400 ANL-6477  
CHEMICAL-METALLURGICAL PROCESSING  
Steunenberg, R. K., Burris, L. Jr., et al.  
(Argonne National Lab. Illinois)

Pyrometallurgical development is reported on melt refining, processes utilizing liquid metal solvents, supporting chemical investigations, and supporting engineering studies in liquid metal systems. The design and construction of fuel processing facilities for EBR-II are described. Research progress is reported on solubilities in liquid metals, coprecipitation studies, liquid-liquid metal distribution studies, and thermodynamic studies.

- 3.400 THE SOLUTION OF GASES IN LIQUID AND SOLID METALS  
Jenkins, A. B. Australasian Engr. February, 1955.

- 3.400 THE SOLUBILITY OF METALS  
D. H. Kerridge (University Coll., Legon, Ghana)  
J. Nuclear Energy, Pt. B. Reactor Technol., 1:215-20 (Feb 1961)

An account is given of some general conclusions reached from an examination of all available data on the solubility of metals in liquid metals. Solubility values were determined from published binary-phase diagrams. Solubilities show periodic variation with increase in atomic number of the solute, and this periodicity is broadly independent of the nature of the liquid metal. A correlation of solubility ( $x$ ) is found with the solute lattice energy which, in turn, is proportional to the latent heat of fusion ( $L_f$ ). Using as solutes any two transition elements which are horizontally adjacent in the periodic table, the value of  $(\log_e x_2 - \log_e x_1) / (\log_{f1} - \log_{f2})$  is nearly proportional to the absolute temperature for nine of the lower melting liquid metals. This fact may be used to estimate solubility values for which no measurements exist. A number of such estimates are given.

NSA 15:14271

- 3.400 EMPLOYING THE PARAMETERS OF EMPIRICAL FORMULAS THAT RELATE HARDNESS TO TEMPERATURE, DURATION OF LOAD, AND PRESSURE TO DETERMINE THE LIMITS OF SOLUBILITY IN THE SOLID STATE  
V. P. Shisokin and A. E. Nikerov. Translated from Izvest. Vyschikh Ucheb. Zavedenii, Chernaya Met., No. 3, 91-5 (1960) 6p.  
(AEC-tr-4441)

A study was made of the influence of composition on the parameters of empirical equations for solid solutions of Ag in Cd, Hg in Sn and Sn, Cd, and Sb in Pb. Tests indicated that under certain conditions, hardness is related to the diameter of the indentation by an exponential law. Relations are developed to show the time and temperature dependencies. The parameters that relate hardness to load, time duration of application, and the temperature are governed application, and the temperature are governed by the experimental conditions, as well as the composition. The computed values of the parameters are shown graphically as a function of composition (B.O.G.)

NSA 15:11612

- 3.400 PB-131065  
Analysis of Temperature Coefficients of Solubility in Dilute Liquid Metal Solutions, by Strauss, S. W. et al.  
U. S. Naval Research Laboratory. June 1957. 23 p. graphs

Temperature coefficients of solubility taken from the literature were compared with (a) electronegatives of solvent and solute, and (b) relative atomic sizes of solvent and solute, in order to identify the fundamental factor or factors which determine the temperature coefficient of solubility of a solid metal in a second liquid metal. U.S. Gov. Res. Reports Vol. 28, No. 3, page 153.

- 3.400 KAPL-1021 Knolls Atomic Power Lab., Schenectady, N. Y.  
Compatibility of Materials in Liquid Metal; Second Report  
Vail, D. B. Jan. 5, 1954. 69p. Contract W-31-109-Eng-52

Studies previously reported are extended to include a larger selection of pairs of materials and to determine the effect of temperatures up to 950°F upon the compatibility of materials. It was concluded that at a temperature of approximately 850°F and at a liquid metal ambient certain combinations of ceramals (ceramic plug metallic binder) showed negligible wear or surface damage and no apparent transfer of materials. At lower temperatures, some combinations of non-metallic materials, metallic materials, and ceramals indicated satisfactory compatibility characteristics during boundary lubrication.

NSA 11:2447

- 3.400 THE SOLUBILITY OF HYDROGEN IN CERTAIN LIQUID METALS  
Yao, Y. L., J. Chem. Phys., v. 21, 1953.

- 3.400 See Also: 1.120, 4.311, 4.411, 5.300, and 6.160.

- 3.400 KAPL-M-LFE-10  
The Solubility of Helium Gas in Liquid Sodium. Leo F. Epstein.  
Oct. 30, 1951. Changed from OFFICAL USE ONLY Nov. 30, 1956. 12p.

Equations are deriyed for the computation of the solubility of He in liquid Na from 450 to 900° F at one atmosphere pressure.

---

3.410 MERCURY (Hg)

- 3.410 Liquid Metal Research  
NASA-Lewis (NASA-AEC Liquid Metals Corrosion Meeting, Dec. 1961 at BNL)

Hg corrosion loops and capsules; includes solubility study.  
TID-7626 (Part 1) (AGN Lib. 2-2786)

- 3.410 (Russian ) Solubility of Metals in Mercury. V. P. Gladyshev.  
Fizika Metallov i Metallovedenie, v. 9, June 1960, p. 852-860.

Using as examples Li, Na, K, Rb, Cs, Cu, Ag, Au, Mg, Ca, Sr, Ba, An, Cd, Al, Ga, In, Tl, Sn, Pb, Bi and Pt, it is shown that solubility in Mg depends on the structure of the outer electron shell, the strength of lattice bonds, the liquid state structure and the momentum of its ions.  
32 ref. (Pl2e, 3-71; EG-a38, Hg)

- 3.410 ORNL-2871  
Solubilities of Selected Metals In Mercury: Hermex Process  
Messing, A. F., Dean, O.C.  
(U.S. Atomic Energy Commission Rep., 1960.

The solubilities of U, Th, Gd, Sm, and Nd in Hg were determined from 25 to 356°C to evaluate the feasibility of the Hermex process as a method for fuel processing. Equations of the form  $\log. \text{solubility (wt.-%)} = a + b/T$  were developed for these metals. Integral heats of soln. were calculated for each. The solubilities of Ru, Pd, Zr, and Mo in Hg saturated with U were also determined; however, the low solubility of Zr and Mo gave soln. with a concn. below the limit of detection in the analytical method used, and therefore their values are reported as an upper solubility limit. U solubility in a 0.1 wt.-% Mg amalgam was  $1.2-1.5 \times$  Hg alone. When U and Th were present in the same Hg soln., their solubilities were mutually depressed. 19 ref.--R.J.J.

MA 28:348

NSA 14:17931

- 3.410 APPLICATIONS OF ULTRASONIC ENERGY, Progress Report #14 Covering Period from February 1, 1959 to March 31, 1959 Apr. 1959.  
45 p. Contract AT(3001)-1836. \$7.80 (ph), \$3.30(mf) OTS. Aero-projects, Inc., West Chester, Penna.

Additional measurements of the ultrasonic dissolution rate of thorium in mercury showed the rate of attack to be significantly higher at the boiling point of mercury than at lower temperatures. Under the conditions of the experiment, the rate of attack was independent of the exposure time. The rate of ultrasonic erosion of AISI 304 stainless steel in boiling mercury was found to be somewhat lower than the rate at 150°C, confirming the previously observed trend toward reduced erosion rate with increasing temperature. On the basis of current data, it appears that ultrasonic leaching of a simulated alumina waste containing cesium can be effectively accomplished at a power level of 100 watts in 24 hours.

NSA 13-21-18904  
NYC-2568

- 3.410 THE SOLUBILITY OF PLUTONIUM IN MERCURY  
D. F. Bowersox and J. A. Leary  
J. Inorg. and Nuclear Chem. 9, 108-12 (1959) Jan. 13:956.

- 3.410 ATTACK OF UNSTRESSED METALS BY LIQUID MERCURY  
J. F. Strchan and N. L. Harris. J. Inst. Metals 85, 17-24 (1956)  
(Paper No. 1715)

The solubilities and weight losses in the absence of air at room temperature of most of the metallic elements in static liquid Hg were determined, usually to 0.001%, by chemical analysis of the solutions and by weighing the specimens. The solubilities show a periodic relationship with the atomic number, and there are indications that this can be related to the inner electronic shell structure. In general, the solubilities of the B sub-group elements exceed those of the true metals, while this latter group the transition metals show the lowest values. When attack occurs, it involves wetting, surface amalgamation, solution and occasionally combination and intergranular penetration. Oxidation brought some metals of solution in Hg and led to ambiguities. Exposure to air can result in a form of mass transfer. No significant changes occurred in the mechanical properties of Fe, Mo, some steels, and Ni alloys after 2000 hrs in Hg at 500°. Ni suffered a decrease in maximum stress, yield stress, and elongation of about 50%. Severe cavitation erosion of metals and alloys, normally resistant to Hg, occurred at room temperature on the application of 30 kc/sec ultrasonic vibrations.

CA51-981h

- 3.410 DIFFUSION AND CHEMICAL CONTROL IN THE DISSOLUTION OF METALS IN MERCURY  
Bennet, J. A. R., and J. B. Lewis  
J. Chim. Phys., 55:83-89; discussion 89-90 (1958)

The constants of dissolution of Pb, Sn, and Zn in Hg were compared with those of the dissolution of benzoic acid in water since the latter is known to be a process of controlled diffusion. The correlation between the data from the systems Sn-Hg, Pb-Hg, and benzoic acid-water, was sufficient to establish that the rates of dissolution of Sn and Pb in Hg represent a controlled-diffusion process. With Zn-Hg, dissolution is partly a chemical process and it was shown that, with single, cylindrical Zn crystals, the rate of dissolution was different for the different crystallographic faces. The same phenonemon was qualitatively observed with Bi and Cd.

MA 26:663

- 3.410 AERE-CE/R-1998  
Transport and Chemical Control in the Dissolution of Metals In Mercury. J. A. R. Bennett and J. B. Lewis. June 1957. 48p.  
United Kingdom Atomic Energy Authority. Research Group.  
Atomic Energy Research Establishment, Harwell, Berks, England

The dissolution rates of tin, lead, and zinc in mercury and of benzoic acid in water and aqueous sucrose were investigated under conditions which solid cylindrical specimens are held stationary and concentric cells containing the solvent are rotated about them at predetermined speeds. The results indicate that the dissolution of tin and lead in mercury is transport controlled. The mass transfer coefficient data for these and the benzoic acid systems were correlated by the expression

$$\frac{KL}{v} = 0.018 \frac{Lu}{v}^{0.6} \frac{v}{D}^{-0.5}$$

The zinc data do not fit correlation due to the influence of the mean chemical rate with an activation energy of the order of 10 kcal/mole. Qualitative results obtained with single and multi-crystalline specimens of zinc indicate that different crystal planes of the zinc lattice dissolve at different rates. Data were also obtained for the dissolution of benzoic acid in water and

aqueous sucrose by use of the expression

$$\frac{KL}{v} = 0.135 \frac{Lu}{v}^{0.6} \frac{v}{D}^{-0.6}$$

NSA 14:5064

- 3.410 SOLUBILITY OF METALS IN MERCURY  
V. P. Gladyshev. *Fizika Metallov. i Metallovedeniye*, Vol. 9, No. 6, pp. 852-860. 1960. Submitted December 23, 1959, Association: (Kazakh State University im. S. M. Kirov.)

- 3.410 Private Communication to L. R. Kelman, compilation and discussion of unpublished data of A. J. Nerad and Associates at General Electric. L. F. Epstein, also review of literature.

Zirconium alloys readily with Hg. The equilibrium solubility of Zr in Hg varies from 5 ppm at 350°C (622°F) to 16 ppm at 550°C (1022°F).

- 3.410 AERE-R/R-2274  
Gt. Brit. Atomic Energy Research Establishment, Harwell, Berks, England  
Tests on an Experimental D. C. Pump for Liquid Metals by D. A. Watt et al. May 1957. 52p.

The experimental equipment and techniques of construction and measurements are briefly described. A comprehensive survey of pump performance with graded field to control and current losses is given, together with some results for a simple baffle system. Field grading gives the better result, the maximum efficiency being near 40% with Hg in an 18/8 stainless steel channel with 25 gpm flow. It is considered that a baffle system of improved form may have some advantage in pumps of smaller length/width ratio. For the pump described the ratio,  $c/b = 7/3$ . Gas entrainment tests are described: these showed only small changes in pump performance. Hydraulic friction losses from water flow tests are recorded.

NSA 12:213

---

3.420 POTASSIUM (K)

To be expanded in the supplement.

---

3.430 SODIUM (Na)

- 3.430 AD-284340  
HIGH TEMPERATURE PROPERTIES OF SODIUM AND POTASSIUM, PROGRESS REPORT No. 7, APRIL 1 - JUNE 30, 1962  
Ewing, C. T., Stone, J. P., and others (Naval Research Lab., Washington, D. C.) August 27, 1962. 6p., incl. tables. 4 refs. (NRL Report No. 5844)

An experimental program is underway to measure several thermophysical properties of sodium, potassium, and their vapors at elevated temperatures. The status of each property test is discussed, and preliminary values are reported for the density of liquid potassium from 1564° to 2282°F, and for the equilibrium solubility of columbium and zirconium in liquid sodium from 1470° to 2507°F. (Author)

- 3.430 Liquid Metals: Part V, The Role of O<sub>2</sub> Films in the Wetting of Fe, Co, and Ni by Liquid Na and by Solutions of Ba and Ca in Liquid Na, by C. C. Addison, et al., J. Chemical Society 2699-705, July 1962.

Discusses wetting at different temperatures apparently resulting from Na reaction in removing oxides. Additions of small amounts of Ca (> 0.07%) or Ba to Na(l) influences wetting rates profoundly.

NSA 16:25782



- 3.430 Determination of Oxygen in Alkali Metals and Their Alloys by Mercury Extraction  
Malikova, E. D. and Turovtseva, Z. M.  
(V. I. Vernadskii, Inst. Geochem. and Anal. Chem. Moscow)  
Trudy Komissii Anal. Khim., Akad. Nauk S.S.S.R.,  
Inst. Geokhim. i. Anal. Khim. 10, 91-6 (1960)

The method of Pepkowitz and Judd (CA 45, 66i) was employed; the sensitivity was  $1 \times 10^{-3}\%$ , while accuracy was 10%.

CA 55:6247d

- 3.430 STUDY OF LOW SOLUBILITIES IN A FUSED METAL BY SAMPLING AT CONSTANT TEMPERATURE FROM THE LIQUID PHASE: APPLICATION TO THE GALLIUM - SODIUM SYSTEM.  
Emile Rinck and Pierre Feschotte. Compt. rend. 250, 1489-91  
(1960) Feb. 22. (In French)

The low solubility of any solid constituent in a fused metal can be measured by sampling the fused metallic phase at a instant temperature and then analyzing the samples. Factors affecting the sampling technique were studied using the gallium - sodium system. NSA 14:12845

- 3.430 Kovacina, T. A., Miller, R. R., "The Solubility of Nickel in Sodium by a Tracer Technique," Nuclear Sci and Eng. 10, 163-6(1960).

The solubility of nickel in liquid sodium of known purity under static near is-thermal conditions was determined by a radioactive technique using  $\text{Ni}^{63}$  as the tracer. The solubility varied from 0.004 to 0.20 ppm over the temperature range of 200 to 600°C. NSA 15:22300

- 3.430 DETERMINATION OF THE SOLUBILITY OF OXYGEN BEARING IMPURITIES IN SODIUM, POTASSIUM, AND THEIR ALLOYS.  
D. D. Williams, J. A. Grand, and R. R. Miller.  
J. Phys. Chem. 63, 68-71 (1959) Jan.

NSA 13:9759

- 3.430 Grand, J. A. et al.  
THE SOLUBILITY OF TANTALUM AND COBALT IN SODIUM BY ACTIVATION ANALYSIS  
J. Phys. Chem. 63, 1192-94 (1959). July

NSA 13:17902

- 3.430 NAA-SR-Memo-2061, The Determination of Oxygen in Sodium--A Critical Review of Analytical Methods, Smith, C. R. F.,

Seven means of measuring the sodium monoxide content of liquid sodium are reviewed. Data relating to the solubility of sodium monoxide in sodium are collected. Methods and data are criticized from the standpoint of precision and systematic interferences. It is concluded that there is no proved method which is free from systematic interferences and which is capable of measuring oxygen in sodium in quantities of 400 ppm or less. It is recommended that a program be undertaken to make comparative tests of all analytical methods and to determine the solubility of  $\text{Na}_2\text{O}$  in Na from 10 to 2000 ppm oxygen.

- 3.430 AECU-3519  
Los Alamos Scientific Lab., New Mexico  
The Partition of Oxygen Between Sodium and Tantalum by Holley,  
Charles E. Jr., July 2, 1957. 8p. Contract W-7405-eng-36.

- 3.430 NAA-SR-Memo-6064, CALCIUM NITRIDE IN SODIUM (Jan. 20, 1961)  
Mackey, T. L.

Below 300°C, nitrogen did not react with Ca dissolved in sodium. In the range 355 to 720°C, dissolved Ca reacted with nitrogen in the cover gas forming a relatively insoluble compound, probably  $\text{Ca}_3\text{N}_2$ . Calcium nitride precipitation continued until the reactant present in the least amount was exhausted. Saturation solubility of calcium nitride in sodium appears to be between 100 to 200 ppm, and does not appear to be a function of temperature in the range of these experiments. It is possible that the numbers represent particulate  $\text{Ca}_3\text{N}_2$  suspended in sodium. The solubility of calcium in sodium as reported was verified. NSA 15:2165

- 3.430 KAPL - 1653  
SOLUBILITY OF SODIUM MONOXIDE IN LIQUID SODIUM, Salmon  
O. N. and T. J. Cashman, Jr. (General Elec. Co., KAPL,  
Schenectady, N. Y., U. S. Atomic Energy Comm. (1956), 29 pp.

The solubility was determined over the temperature range 115-495°C by the analytical method of Pepkowitz and Judd. The Na handling technique and equipment used were similar to those described by Keenig and Vandenberg. Application of the method of least squares to the data obtained gave the equation  $\log y = 1.266 - (1816/T)$ , where y is the solubility of  $\text{Na}_2\text{O}$  in Na, expressed as wt. % O in Na, at T°K. The results are compared with previously reported values. A type-347 stainless steel (I) container was used to hold the Na and small addition of  $\text{Na}_2\text{O}_2$  which were under a blanket of A. Samples were taken in Pyrex glass and in I tubes. The latter gave higher results, possibly because of migration of O-bearing impurities from the steel and their subsequent reaction with Na. A corrosion study on I was run simultaneously with the solubility tests. Results indicate that the major problem in a I piping system for Na would be the plugging of restricted sections by accumulated insol. corrosion products. The problem of leaks or loss in structural strength as a result of corrosion appears secondary. CA 51:7108

- 3.430 The Solubility of Sodium Hydride in Sodium by Williams, D. D. et al  
(Naval Research Laboratory, Washington, D. C.) NRL-Memo-424  
J. Phys. Chem. 61, 379-81 (1957).

The solubility of NaH in Na is given in graphic form. The solubility is approximately 1.5 wt. % at 400°C and in excess of 4 wt% at 450°C. The results demonstrate a possible source of error in present Na analysis for O by the amalgamation method. The error is not necessarily predictable in a sample drawn directly from saturated Na unless precautions are taken to prevent disson. of hydride during handling and cooling.

CA 51:10195

- 3.430 KAPL-1807  
Knolls Atomic Power Laboratory, Schenectady, N. Y.  
Solubility of Carbon in Sodium at Elevated Temperatures, by J. G.  
Gatton, June 30, 1957. 13p. Contract W-31-109-Eng -52.

An investigation was conducted to determine the solubility of carbon in sodium. This information was required to determine the difference in carburization of stainless steels between that caused by soluble carbon and that caused by suspended carbon. The data indicated that all carbon in amounts  $< 5\mu$  was, in fact, sodium-soluble carbon. The solubility of carbon in sodium under the experimental conditions varied from 32 to 74 ppm in the temperature range 147°C to 700°C. The variation in the solubility, (S - ppm) of carbon with temperature may be expressed in  $S = 4.96 - 6.21 \times 10^2/T$  at 0.003% oxide content, and as  $\ln S = 5.61 - 3.76 \times 10^2/T$  at 0.026% oxide content.

NSA 12:2736

3.430. SOLUBILITY OF CONSTRUCTION MATERIALS IN SODIUM

Bos, Bogard, Grand, Lokkart, Miller, and Williams  
Met. Yudernoi Energet. i Deistrie Obluchen. na Materialy (Moscow;  
Gusudarst. Nauch. - Tekh. Izdatel. Lit. Chernoi i Tsvetnoi Met.)  
Sbornik, pp. 395 - 414. 1956

- 3.430 Bos, Bogard, Grand, Lokkart, Miller and Williams  
Solubility of Construction Materials in Sodium  
Met. Yadernoi Energet. i Deistvie Obluchen. na Materialy (Moscow;  
Gosudarst. Nauch.-Tech. Izdatel. Lit. Chernoi i Tsvetnoi Met)  
Sbornik 1956, 395-414. Referat. Zhur., Met. 1957, Abstr. No. 4785.

The solubility of Fe in molten Na and Na containing  $\text{Na}_2\text{O}$ , and NaOH, and solubility of corrosion-resisting steel components in Na were investigated at various temperatures. The solubility of Fe in Na was determined by measuring radioactivity of Na in the molten state in contact with the materials containing the radioactive isotope  $\text{Fe}^{59}$ . Isotopes  $\text{Co}^{60}$ ,  $\text{Ta}^{182}$ ,  $\text{Sb}^{124}$ ,  $\text{Cr}^{51}$ ,  $\text{Sn}^{121}$ ,  $\text{Ag}^{110}$ , and  $\text{Zn}^{65}$  were also used for detn. of the solubilities of the components of the steel. Experiments were also made to study the isothermal exchange of Ta between Ta and stainless steel immersed in a molten Na bath.

CA 52:14478

- 3.430 NP - 5601  
Progress Report No. 27 for February and March 1955. J. W. Mausteller,  
ed. Apr. 22, 1955. 62p. Contract NObs-65426.

Tests on the Mark B 3000-Kw steam generator are described, including a circulating cold trap and plugging indicator, system cleaning, pump performance, NaK furnace tube failure, boiler water analysis, and heat transfer. Engineering studies are summarized on vent and drain line closures, NaK cross flow exchanger, development of EM pumps, pressure gages, wetting with alkali liquid metals, thermal shock, bellows testing, valve cleaning and testing, and thermal insulation tests in liquid Na. The depression of  $\text{Na}_2\text{O}$  solubility in Na by K is discussed. Further studies on inhibition of mass transfer of radioactive stainless steel constituents in Na are described. The removal of residual radioactive Na with Na flushes was studied. Further results on radioactive leak contamination and the reactions of molten Zr in water are reported.

- 3.430 AD 213 341  
The Solubility of Oxygen in Sodium and Sodium-Potassium Alloy  
Noden, J. D. and Bagley, K. Q.  
United Kingdom Atomic Energy Authority (Ft. Brit.)  
Report No. R & DB (C) TN-80  
20 July 1954, declassified 1958. 7p. illus. tables  
TAB 15 October 1959:5233

The solubility of oxygen in sodium has been determined in the temperature range 130-540 C, and of oxygen in sodium-potassium alloy in the range of 20-176 C, using apparatus in both glass and stainless steel. The results suggest that the solution formed approximates to an ideal solution, but that the partial heat of solution changes abruptly at 260-270 C. Sources of error encountered during the use of the glass apparatus have been investigated.

- 3.430 RDB(C)/TN-33  
Gt. Brit. Culcheth Lab., Culcheth, Lancs, England  
The System Sodium-Oxygen. A Review of Progress to March 1, 1953.  
Oliver, D. S. and J. D. Noden. April 30, 1953. 13p.

The solubility of  $\text{O}_2$  in liquid Na is being investigated by a method previously employed by Williams. Samples prepared by filtration are analyzed by a method of amalgamation of the Na and flotation and estimation of the oxide. Insufficient results are as yet available to ascertain the complete shape of the liquidus in the  $\text{Na-O}_2$  system.

NSA 11:11060

3.430

**KAPL-M-EGB-16**

Knolls Atomic Power Lab., Schenectady, N. Y.

Aluminum Bearing Alloys in Sodium. Report No. 2 on Evaluation of the Behavior of Aluminum in Sodium. Problem No. 28.

Brush, E. G., April 6, 1954. 15p. Contract W-31-109-Eng-52.

Simulated bearing tests have shown that certain Al base alloys have attractive bearing properties for service in Na and NaK. Previous corrosion tests have shown that the behaviour of Al in Na is greatly influenced by the presence of stainless steel. To study this influence under simulated bearing conditions, non-rotating sleeve and journal tests were run in Na at 300, 400 and 500°C. Additional tests were made to determine the solubility of Al in Na as a function of temperature. The tests reaffirm previous findings that at temperatures above 400°C, the high corrosion rate of Al base alloys prohibits their use in Na-stainless steel systems.

---

3.440 SODIUM-POTASSIUM ALLOYS (NaK)

3.440 NaK PRECIPITATION INDICATOR TEST SYSTEM AND EXPERIMENTS TO DATE (NAA-SR-Memo-5472)

G. M. Kikin (AI) July 13, 1960. 37p.

Solubilities and plugging of NaK in a test loop to 1000°F.

NSA 15:13924

3.440 Determination of Oxygen in Alkali Metals and Their Alloys by Mercury Extraction

Malikova, E. D. and Turovtseva, Z. M.

(V. I. Vernadskii, Inst. Geochem. and Anal. Chem. Moscow)

Trudy Komissii Anal. Khim., Akad. Nauk S.S.S.R.,

Inst. Geokhim. i. Anal. Khim. 10, 91-6 (1960)

The method of Pepkowitz and Judd (CA 45, 66i) was employed; the sensitivity was  $1 \times 10^{-3}\%$ , while accuracy was 10%.

CA 55:6247d

3.440 DETERMINATION OF THE SOLUBILITY OF OXYGEN BEARING IMPURITIES IN SODIUM, POTASSIUM, AND THEIR ALLOYS.

D. D. Williams, J. A. Grand, and R. R. Miller, J. Phys. Chem. 63, 68-71 (1959) Jan.

NSA 13:9759

3.440 Siliconizing of Metals in Liquid NaK by Fisher, E. S. et al (Argonne National Lab., Lemont, Ill.) U. S. Atomic Energy Commission TID-7526, 268-81 (1957).

A description of the method and apparatus used to immerse samples of U in molten NaK without contaminating the surface of the specimen. Si is added to the bath in controlled amounts. Present method produces corrosion, but an excellent means of introducing Si in amounts for preparing single crystals of U.

CA 51:11956

3.440 LIQUID-METALS PHYSICAL PROPERTIES PROGRAM

R. Cleary, Pratt & Whitney Aircraft

Notes on Conference on Properties of Alkali Metals at BMI, April 1961

Solubility of gases in liquid metals, and thermodynamic properties of NaK.

3.440 IGR-TN/W-454

Gt. Brit. Windscale Works, Sellafield, Cumb., England

Mass Transfer in Liquid Metal Circuits. A Review of Progress in Initial Studies by Draycott, A. and P. D. Rich. Jan. 1957. 12p. (IGC-FRDC/P-217; IGC-SGDC/P-8)

Significant mass transfer of stainless steel constituents, and to a lesser extent of Zr has been measured in NaK circuits. In the first instance, at least, the oxide content of the liquid metal was a contributory influence. Solubility-temperature.....

3.440 NP-6458

RESEARCH ON LIQUID METALS AS POWER TRANSMISSION FLUIDS. Quarterly Progress Report No. 4 (for) June to September 1957. R. C. Kumpitsch, J. Huthsteiner, and D. Lombardo. Sept. 1, 1957. 27p.

The General Electric Co. has provided a new facility in which to determine the feasibility of using Na-K alloys, especially NaK 77, as a power transmission fluid for high temperature applications. The facility, complete with an integral disposal and clean-up area, provides a more efficient, clean, confined, and safe location in which to undertake this development. Operation in the new test area is scheduled for 16 September 1957. Initial tests conducted with the single cylinder NaK test pump revealed that modification and improvement of this equipment was necessary to insure consistent 3000 psi 1000° F operation. All design changes being made to the single piston pump tester are described in detail in the report. An investigation was conducted to determine the most suitable high temperature wear tester commercially available for preliminary screening of materials and for evaluating the lubricity effects of additives in NaK 77. Several of the wear testers being considered have been evaluated. This investigation has not been completed. The results to date are included in this report. Future effort will be directed toward getting the Single Piston NaK Pump tester into operation and the selection and purchase of the most desirable wear tester.

3.440 NP - 5921

PROGRESS REPORT NO. 33 FOR FEBRUARY AND MARCH 1956. W. J. Posey, ed. Apr. 9, 1956. 57p. Contract NObs-65426

Progress is reported on the tests made on models of the S2G steam generators. Modifications of a 1000 KW test unit were made to permit adequate testing of the 3000 KW generators. The cyclic test program for the S2G is outlined. Typical Na flow data are given for the cyclic testing of the S2G evaporator. The operational history of this evaporator is also discussed. Progress is also reported on research pertaining to liquid metal system components, including fundamental heat transfer studies and component development and testing. Diagrams are given of the steam generators and tube joints. Operating characteristics of the liquid metal system are tabulated. The ability of transition welds to withstand the rapid temperature changes anticipated during scram conditions was studied. The suitability of stainless steel bellows for use in 8-in. S2G sodium valves was also studied. Results are given of 14 runs to determine the minimum velocity necessary to remove entrained gas by forcing it downward through the 5½-ft vertical leg for separation in the lower expansion tank. The nitriding of metals in Na is also discussed. The weight losses of Be specimens in 900° F Na are shown. A study was made of the characteristics of water-NaK leaks and applicable sealing methods. Data are given on the corrosion rate of Cr-Mo steel samples in NaK. It was found that the solubility of O in NaK is dependent on K concentration.

3.440 AD-213341  
The Solubility of Oxygen in Sodium and Sodium-Potassium Alloy  
Noden, J. D. and Bagley, K. Q.  
United Kingdom Atomic Energy Authority (Ft. Brit.)  
Report No. R & DB (C) TN-80  
20 July 1954, declassified 1958. 7p. illus. tables  
TAB 15 October 1959:5233

The solubility of oxygen in sodium has been determined in the temperature range 130-540 C, and of oxygen in sodium-potassium alloy in the range of 20-176 C, using apparatus in both glass and stainless steel. The results suggest that the solution formed approximates to an ideal solution, but that the partial heat of solution changes abruptly at 260-270 C. Sources of error encountered during the use of the glass apparatus have been investigated.

3.440 AERE-ED/R-1856  
Gt. Brit. Atomic Energy Research Establishment, Harwell, Berks, England  
A. C. Liquid Metal Pumps for Laboratory Use  
Watt, D. A. March 19, 1953. Revised Jan. 24, 1956. 33 p.

Two types of single phase a-c electromagnetic pump for liquid metals are described, a leakage reactance model and a combined pump and transformer. The NaK alloy test rig is briefly described and methods of pump construction detailed. Test results are curves for pumping NaK alloy at temperatures below 70 C are included, and it is shown that the combined form is the more effective pump. One of these models with a single loop secondary winding had a maximum efficiency of 11% with output 10 gals/min. at 13 lb/in.<sup>2</sup> pressure rise, input 650 watts, 9.0/7.5 amps at 180/195 volts. A maximum pressure rise of nearly 30 lb/in. is recorded for the first model of this form.

NSA 10:11171

3.440 Solubility of Sodium Monoxide in NaK  
Rodgers, S. J. and J. W. Mausteller  
Mine Safety Appliances Company, Callery, Penna. Technical Report  
No. 47 Contract NObs-65426. March 15, 1956. 9p.

The concentration of oxygen (added as Na<sub>2</sub>O) in NaK-24 (24 wt.% potassium) and NaK-44 was studied as a function of temperature. Oxygen concentrations are higher for higher temperatures. Curves are presented for oxygen concentration versus temperature and potassium content for NaK-24, NaK-44 and NaK-78. Up to 550°F the oxygen concentrations are independent of potassium content of the sodium, but above 550°F the curves diverge to reach oxygen saturations at 1000°F of 0.20, 0.15, 0.085 and 0.050 wt. % O<sub>2</sub>, respectively, for sodium, NaK-24, NaK-44 and NaK-78. These data can be applied to the problem of oxide precipitation by a leak from a third-fluid NaK system to a sodium system high in oxygen content. Below 0.010 wt. % O<sub>2</sub> in the sodium there would be no problem. Above this value precipitation would depend on the potassium content, temperature, and oxygen content, but the effect would be of little consequence in a well-designed sodium system.



4.000

EFFECT OF DESIGN AND FABRICATION

PARAMETERS ON CORROSION BY LIQUID METALS





4.000 EFFECT OF DESIGN PARAMETERS ON CORROSION BY LIQUID METALS

4.000 AD278803  
Materials Central-ASM Metallurgical Educational Lectures (Final)  
ASD TDR62-396

A series of lectures on failure analysis is presented. Causes, cures and preventive measures of corrosion are discussed. Also lubrication included.

---

4.100 MERCURY LOOP AND DESIGN

4.100 SNAP-8 MATERIALS TASK GROUP REPORT, AD-HOC COMMITTEE REPORT  
L. Rosenblum, NASA (Chairman)  
Pub. by Aerojet General Corporation, Azusa  
August 20, 1962

Review of critical problem areas relative to long life mercury and NaK systems. The neglected development of the NaK system and the poor corrosion resistance of the Haynes 25 alloy in mercury were discussed.

4.100 AGC-0584-04-2  
MERCURY CORROSION LOOP TESTING PROGRAM. QUARTERLY REPORT  
JANUARY 1 THROUGH MARCH 31, 1962  
(Aerojet-General Corp., Azusa, Calif.)  
April 27, 1962. Contract NAS 3-1925. 34 p.

The Mercury Corrosion Loop Testing Program was continued. Materials to be tested in the 10 forced-convection test loops were selected; the materials are: Haynes 25, 9Cr-1Mo alloy clad with Type 316 stainless steel, AM-350 stainless steel, and niobium clad with Type 316 stainless steel. The eight-test-cell facility was completed and all utilities were installed. Pneumatic and electronic instrumentation for all test cells was installed and calibrated. Fabrication was initiated on the first four Haynes 25 loops. The first loop was 85% assembled at the end of the quarter. A centrifugal pump made from Type 316 stainless steel was tested; bearing modifications were made to improve operation. (auth)

4.100 AGC-0584-04-3  
MERCURY CORROSION LOOP TESTING PROGRAM. THIRD QUARTERLY  
REPORT, APRIL 1 - JUNE 30, 1962  
(Aerojet-General Corp. Power/Equipment Div., Azusa, Calif.)  
August 6, 1962. Contract NAS 3-1925. 26 p.

The fabrication and testing in the Dynamic Mercury Corrosion Loop Testing Program are reported. Operation of the first ten loops to be tested was begun, and a second loop was fabricated. Four of the test loops will be fabricated from Haynes 25 alloys while the remaining six will be fabricated from 316 stainless steel - clad (or unclad) Cr-Mo alloys or 316 stainless steel-clad Nb. (J.R.D.)

4.100 See Also: 2.310, 2.350, 5.110, and 1.630.

- 4.100 BNL-756  
LIQUID METAL RESEARCH AT NASA-LEWIS RESEARCH CENTER  
James P. Lewis, Lewis Research Center, Cleveland, Ohio  
Second Annual High Temperature Liquid Metal Heat  
Transfer Technology Meeting, BNL, May 17 and 18, 1962

The paper outlines the major liquid metals research and development efforts at Lewis Research Center. The work includes: a Two-Phase Sodium Loop for flashing sodium vapor; the Sodium Turbine Facility using refractory metals; Pump Test Facilities including one low pressure K pump and one high pressure Na pump; Alkali Metal Heat Transfer Facility using EM pumps and Cb-12r above 1500°F and type 316 stainless below; A Space Radiator and Condenser Facility using a NaK loop for boiling potassium; Bearing and Seal Studies using liquid Na environments; Mercury Programs relative to the radiator problem in zero gravity similar to SNAP VIII conditions; and several Materials Support Programs directed to advanced materials and refractory metals for all alkali metals, and Hg loop corrosion.

- 4.100 AEC-tr-5382  
EXAMINATION APPARATUS FOR CAVITATION TESTS IN LIQUID METALS  
Conference of Iron and Steel in Liquid Metals, Yunoshin Imai  
(Tohuko Univ. Sendai) Yoshimitsu Kikuchi and Tetsuro Isizaki.  
NIPPON GENSHIRYOKU GAKKAISHI 4:77-84. Feb. 62. In Japanese.

To obtain exact and detailed information on a possibility of the occurrence of cavitation and further on a factor upon the cavitation in liquid metals, a test apparatus consisting of a magneto-struction vibrator and the ultrasonic oscillator (18-22 kc) was assembled. From the results of testing in liquid metals, such as Pb, Bi and Hg, it was confirmed that the erosion which is considered to be due to cavitation effect, takes place. The macro-aspects of the cavitation damage differed widely by the kind of liquid metal, and the cavitation erosion effect became more marked with the rise of test temperature and with the increase of the contents of elements in the tested materials which are resolvable into liquid metals. It was concluded that the cavitation by liquid metal must be considered in the design of a liquid metal fuel reactor.

NSA 16:13537

#### 4.110 CORROSION DEPENDENCE ON SYSTEM CONFIGURATION

- 4.110 KAPL-M-WLF-5  
Knolls Atomic Power Laboratory, Schenectady, N. Y.  
Examination of the Natural Circulation Steam Generator From the Liquid Metal Heat Transfer Test Facility at Alplaus, New York.  
Report No. 2  
Callahan, E. J. and W. L. Fleischmann  
September 12, 1953. Changed from Official Use Only Oct. 8, 1956. 35p.  
Problem No. 70: Investigation of the Causes of Cracking in the Natural Circulation. Contract W-31-109-Eng-52

The first structural failure of a heat exchanger used in the Alplaus liquid metal system is discussed. The metallurgical examination revealed failure of two Type 347 stainless steel tubes (NaK outside, mercury inside) and two tube sheets. The location of the failure was confined to the hot end and the area around these two hottest tubes. Judging by the fracture appearance, the majority of the cracks were caused by thermal cycling. Further studies are under way to establish more definitely the cause of the failure.

NSA 11:3791

- 4.110 See Also: 1.520, 1.530, 2.310, and 2.400.

- 4.111 See Also: 1.320, 2.310, 3.410, 5.400, and 7.420.

- 4.110     EXAMINATION OF THE FORCED CIRCULATION STEAM GENERATOR FROM THE LIQUID METAL HEAT TRANSFER TEST, at Alplaus, N.Y.  
Placzkowski, E. J.  
April 11, 1954. Changed from Official use only Oct. 8, 1956. 19 p.  
Sub-Project No. 70: Investigation of Alplaus Units. Contract W-31-109-Eng-52. Report No. 2  
KAPL-M-EJP-2

The metallurgical investigation of the forced circulation steam generator revealed the failure of two Type 347 stainless steel tubes (air outside, mercury inside). The two tubes were located at the top of the unit and the failures occurred at the tube sheet welds (both "hot" and "cold" ends). The cracking was attributed to thermal cycling involving temperatures and stresses above the design values.

- 4.110     BNL-756  
DEVELOPMENT PROBLEMS OF SNAP REACTOR SYSTEMS  
G. M. Anderson, Atomic Energy Comm., Div. Reactor Development  
Second Annual High Temperature Liquid Metal Heat Transfer Meeting,  
Brookhaven Nat. Laboratory, May 17, 1962

A review of major problem areas in the hardware development of current SNAP systems. The temperature vs endurance life relationships are covered, primarily from the reactor performance aspect. Space environment aspects of both dynamic conversion and direct conversion power systems are included. NaK and mercury loop components are mentioned.

- 4.111     MND-P-2382  
SNAP 1 POWER CONVERSION SYSTEM MATERIALS DEVELOPMENT  
V. F. Hambor and J. J. Owens  
The Martin Co. Purchase Order OE-0101

Because of the environmental conditions imposed on the SNAP 1 Power Conversion System, it was necessary to conduct a program to determine the materials to be used in fabricating the system. The very small operating clearances resulting from miniturization of the components made it imperative that formation of any corrosion products be minimized to avoid plugging of small flow passages and interference between parts. In addition, nonmetallic materials had to be evaluated to provide a reliable insulation system for the electrical components and a method for insuring that mercury did not enter the stator windings of the alternator.

Metallic materials were investigated to determine their resistance to corrosive attack by mercury and the effect of mass transfer due to temperature and concentration gradients existing in the system. Materials evaluated included the refractory metals, carbon steels, and the 300 and 400 series stainless steels. As a result of the metallic materials effort, it was concluded that the corrosion contaminants generated produce a more severe problem than the loss of structural material. At 750 to 800°F, most steels were satisfactory, but at 1000°F, the alloys containing Ni were attacked by Hg, but type 446 steel was resistant.

A nonmetallic materials program was conducted to develop suitable insulation and sealing materials for the alternator stator. It was established that the materials and fabrication techniques developed could satisfactorily protect the stator in the SNAP 1 environment.

- 4.112     NAA-SR-6306  
SNAP II POWER CONVERSION SYSTEM - TOPICAL REPORT #14  
MERCURY MATERIALS EVALUATION AND SELECTION  
J. F. Nejedlik, J. J. Owens

Steels, high temperature alloys and refractory metals were screened to evaluate corrosion resistance for long service in a boiling Hg system. High Mn or Ni containing alloys were among the least resistant materials. The Co base Haynes 25 was resistant for a limited time at 900°F after which an increased corrosion rate was observed.

A study of corrosion kinetics which led to excessive sludge deposition was made. The change of temperature coefficient for mass transfer for many of the structural alloys was proposed to indicate a change of mechanism above 700°F. Diffusion controlled corrosion and crevice attack were suggested from the results.

4.113 To be expanded in the supplement.

4.114 LIQUID METAL CAVITATION PROBLEMS AND DESIRED RESEARCH  
Hammit, Frederick G., American Society of Mechanical Engineers,  
Paper No. 60-HYD-13, 1960, 7 p.  
Rev. of Met. Lit. 17:5

Cavitation of liquid Na, K, Rb, Na-K alloys, Hg, Bi and Pb-Bi alloys as heat-engine fluids versus H<sub>2</sub>O. Temperature, density of liquid, density of vapor, viscosity, surface tension, heat capacity latent heat, thermal conductivity, vapor pressure and bulk modulus. (R2m, 14-60, Hg, Na, Na-b, Bi, Pb-b).

4.114 AEC-tr-5382  
EXAMINATION APPARATUS FOR CAVITATION TESTS IN LIQUID METALS  
Conference of Iron and Steel in Liquid Metals, Yunoshin Imai  
(Tohoku Univ. Sendai) Yoshimitsu Kikuchi and Tetsuro Isizaki.  
NIPPON GENSIRYOKU GAKKAISHI 4:77-84. Feb. 62. In Japanese.

To obtain exact and detailed information on a possibility of the occurrence of cavitation and further on a factor upon the cavitation in liquid metals, a test apparatus consisting of a magneto-structure vibrator and the ultrasonic oscillator (18-22 kc) was assembled. From the results of testing in liquid metals, such as Pb, Bi and Hg, it was confirmed that the erosion which is considered to be due to cavitation effect, takes place. The macro-aspects of the cavitation damage differed widely by the kind of liquid metal, and the cavitation erosion effect became more marked with the rise of test temperature and with the increase of the contents of elements in the tested materials which are resolvable into liquid metals. It was concluded that the cavitation by liquid metal must be considered in the design of a liquid metal fuel reactor.

NSA 16:13537

4.114 PITS IN METALS CAUSED BY COLLISION WITH LIQUID DROPS AND RIGID STEEL SPHERES, Olive G. Engel, (J. Research Nat. Bur. Stand., 1960, (a) 64, (1), 61-72)

Experimental data from the depths of pits produced by Hg drops, water drops, and steel spheres in electrolytic tough-pitch Cu, 1100-0 Al, and 2024-0 Al were used to examine the pit depth/velocity equation developed earlier. Different numerical const. were obtained for flowing projectiles and steel projectiles. Calculated curves were in agreement with experimental data, with the exception of steel spheres against the 2024-0 Al alloy in which work-hardening of the target indicated a mode of pit formation not considered in the development of the equation. HJ

MA 28:487

4.114 NYC-2568  
APPLICATIONS OF ULTRASONIC ENERGY, Progress Report #14 Covering Period from February 1, 1959 to March 31, 1959 Apr. 1959.  
45 p. Contract AT(3001)-1836. \$7.80 (ph), \$3.30(mf) OTS. Aero-projects, Inc., West Chester, Penna.

Additional measurements of the ultrasonic dissolution rate of thorium in mercury showed the rate of attack to be significantly higher at the boiling point of mercury than at lower temperatures. Under the conditions of the experiment, the rate of attack was independent of the exposure time. The rate of ultrasonic erosion of AISI 304 stainless steel in boiling mercury was found to be somewhat lower than the rate at 150°C, confirming the previously observed trend toward reduced erosion rate with increasing temperature. On the basis of current data, it appears that ultrasonic leaching of a simulated alumina waste containing cesium can be effectively accomplished at a power level of 100 watts in 24 hours.

NSA 13-21-18904

- 4.114 PITS IN METALS CAUSED BY COLLISION WITH LIQUID DROPS AND SOFT METAL SPHERES. Engel, Olive G., (J. Research Nat. Bur. Stand., 1959, 62,(6), 229-246)

An equation is given for pit depth as a function of collision velocity for pits formed in soft to medium-hard metal plates as a result of collision with liq. drops and with spheres of the same metal that flow radially after collision. The plate thickness must be between 1.5-2 x and 4-5 x the drop dia. Hg drops were used against Cu, Al, Pb, and steel targets and spheres of Cu, Al, Pb, Zn, and soft Fe against targets of the same materials. The equation can be used to calculate the dynamic compressive YS of soft to medium-hard metals. 15 ref. -HJ.

- 4.114 Selection of Liquid-Metal Pumps by Hammitt, F. G. (Univ. of Michigan, Ann Arbor) Chem. Eng. Progr. 53, 249-53 (1957).

The design and development of large-scale, liquid-metal circulating pumps such as would be suited to application in nuclear power plants have been investigated. Fluid dynamic problems-cavitation and erosion damage to the structural components at the high relative velocities obtained in the pump impeller - were the particular concern.

CA 51:10139

---

4.120 WELD STRUCTURE, BRAZEMENTS, AND CONNECTIONS

- 4.121 NP-7410  
Plugging Leaks Between Water and Third Fluid System (Hg)  
Rodgers, S. J. et al.  
Mine Safety Appliances Co., Callery, Pa.  
Memo Report 92, September 29, 1955, 16p.  
Contract NObs-65426

An investigation was made of sealing methods for leaks between water (or steam) and mercury systems. Leaks simulating tube-to-tube sheet joint cracks were successfully plugged in > 1 hr by adding a commercial boiler sealant (Leakure) or an Fe-Fe<sub>2</sub>O<sub>3</sub> mixture to the water side. Addition of 1 wt. % magnesium + ~ 1 vol. % Leakure to the mercury system gave plugs in either steam or water leaks. Operating conditions were 500 psig (465 F) on the water side and ~ 300 psig 500 F on the mercury side. Pressures were alternated in some cases. Plugs held 500-800 psi differential pressures both at operating water conditions (atmospheric pressure on mercury side) and at room temperature (auth).

NSA 13:11851

- 4.121 SPECIAL SEAL PROGRAMS  
C. M. Allen  
(BMI) (TID-7604 p. 227-31) 1960

The use of dry face seals over the liquid brushing seal is investigated and the use of Hg as a fluid in seals is also discussed.

NSA 15:18166

- 4.121 MECHANICAL COMPONENTS AND DESIGN CONSIDERATIONS  
J. H. Germer and C. R. Stahl  
The Reactor Handbook, Vol. 2, Engineering, Chapter 2.6 p. 323, 1955

Seals: welded, frozen static, frozen rotating, rubber boot, liquid trap, and wobble. Bearings are mentioned.

- 4.130 PRELIMINARY STUDY OF THE FATIGUE OF METALS IN LIQUID METAL ENVIRONMENTS, J. W. Martin and G. C. Smith. Metallurgia 54, 227-32, 238(1956).

A series of expts. with 70/30 brass showed that amalgamation reduced the life at all stresses. The effect appears to be a min. in the region of the fatigue limit and increases rapidly as the stress amplitude is increased. In the amalgamated specimens, intergranular failure occurred over the whole of the fracture surface, although the zone wetted by Hg did not extend to the center of the fracture. In the case of 60/40 brass, specimens were fractured with and without Hg. In the fracture of an amalgamated specimen the path of the cracks tends to follow the  $\beta$ -matrix rather than run through the  $\alpha$ -phase, but in the nonamalgamated specimen the path of the fracture is random. The lower the fatigue stresses, the greater the depth of penetration of the Hg. Tests were run with mild steel in contact with liquid Sn and 18/8 stainless in contact with liquid Na. In the case of the mild steel, the fatigue limit is raised at elevated temp. and life is increased at stresses above the fatigue limit. In contact with liquid Sn, the fatigue limit is lowered and life at stresses above the fatigue limit is reduced. The proportional decrease in life is greatest at the higher stresses employed and least in the region of the fatigue limit. In the case of 18/8 stainless steel in contact with liquid Na, life does not seem significantly different from empty specimens, although a no. of cracks have been observed in specimens contg. Na. 11 references.

CA 51-998a

---

4.140 BEARINGS AND BEARING SURFACES

- 4.140 SPACECRAFT LUBRICATION  
J. F. Judge, Published in Missiles and Rockets, May 13, 1963, p. 27 and 30.

Includes the status of liquid metal lubrication research directed towards space power conversion systems. (Hg, K, Rb, and Li).

- 4.140 MND-P-2379  
SNAP I POWER CONVERSION SYSTEM BEARINGS DEVELOPMENT. Period Covered: February 1, 1957 to June 30, 1959. TAPCO (ER-4054)  
R. Meredith, et. al., June 1960

Liquid mercury, lubricated hydrosphere bearings were selected. Design and performance data are given along with conclusions. NSA 14:26038

- 4.140 Research on Liquid Metals and Other Unusual Materials (Sundstrand)  
J. R. May, NASA TN-D-769, 1960

K & Hg as bearing lubricants.

NSA 15:13283

---

#### 4.200 POTASSIUM LOOP DESIGN

- 4.200 GE 63 FPD66  
ALKALI METALS BOILING AND CONDENSING INVESTIGATIONS  
VOL. II - MATERIALS SUPPORT

J. W. Semmel, Jr., W. R. Young, and W. H. Kearns  
Space Power and Propulsion Section, GE Co., Cincinnati 15, Ohio  
Final Report for period January 1, 1961 to June 30, 1962.  
Published January 14, 1963

Materials support was provided for alkali metals boiling and condensing investigations which required the construction of a 300 KW heat transfer loop from L-605 and a 100 KW loop from the Cb-12r alloy. In addition to the preparation of specifications for these materials and assistance in constructing the heat transfer facilities, experimental investigations were conducted to document several aspects of the materials behavior which were pertinent to the loop construction and operation. Experimental work was performed in the following areas: 1) Aging and embrittlement of L-605, 2) Corrosion of L-605 by potassium, and 3) Corrosion and diffusion bonding of Stellites No. 6 and No. 12 hard facing materials in potassium.

AGN Lib. 3-2299

- 4.200 See Also: 2.320, 5.120, and 5.220.

#### 4.210 CORROSION DEPENDENCE ON SYSTEM CONFIGURATION

- 4.211 To be expanded in the supplement.

- 4.212 To be expanded in the supplement.

- 4.213 To be expanded in the supplement.

- 4.214 Liquid Metal Cavitation Problems and Desired Research  
Hammit, Frederick G., American Society of Mechanical Engineers,  
Paper No. 60-HYD-13, 1960, 7 p.  
Rev. of Met. Lit. 17:5

Cavitation of liquid Na, K, Rb, Na-K alloys, Hg, Bi and Pb-Bi alloys as heat-engine fluids versus H<sub>2</sub>O. Temperature, density of liquid, density of vapor, viscosity, surface tension, heat capacity latent heat, thermal conductivity, vapor pressure and bulk modulus. (R2m, 14-60, Hg, Na, Na-b, Bi, Pb-b).

- 4.214 Selection of Liquid-Metal Pumps by Hammit, F. G. (Univ. of Michigan, Ann Arbor) Chem. Eng. Progr. 53, (1957)

The design and development of large-scale, liquid-metal circulating pumps such as would be suited to application in nuclear power plants have been investigated. Fluid dynamic problems-cavitation and erosion damage to the structural components at the high relative velocities obtained in the pump impeller - were the particular concern

CA 51:10139

- 4.214 WORKING FLUIDS FOR HIGH TEMPERATURE, RANKINE CYCLE, SPACE POWER PLANTS. D. L. Cochran, Aerojet-General Nucleonics, San Ramon, California. Presented at the National Aeronautics and Space Engineering and Manufacturing Meeting (1961)

An analysis is presented of the relative suitability of sodium, potassium, rubidium, and cesium as working fluids... since mercury and steam turbines have experienced blade erosion and since potassium has the lowest tendency to cause erosion, potassium appears to be the best over-all working fluid....



#### 4.220 WELD STRUCTURE, BRAZEMENTS, AND CONNECTIONS

- 4.221 DYNAMIC SHAFT SEALS IN SPACE. FIRST QUARTERLY REPORT FOR PERIOD ENDING JULY 15, 1962  
General Electric Co., Spacecraft Dept.,  
Cincinnati. Contract AF 33(657)-8459. 80 p.

The development of dynamic shaft seals for space applications is considered. The seals considered must operate on high speed to rotating shafts under conditions of high temperature liquid metals and vapors, and near-vacuum environments of space. The 20,000 rpm water seal test rig was designed and analytical investigation of screw seals started. Design layouts were completed on various configurations of the stationary housing-rotating disk and the squeeze seal. The design of the high speed test rig to be used for liquid metal (potassium) testing and its auxiliaries required for liquid operation is described. Water pretesting of rotating fluid ring seals is evaluated. (N.W.R.)

- 4.222 To be expanded in the supplement.

#### 4.230 FATIGUE OF EXPANSION/CONTRACTION COMPONENTS

- 4.230 See: 4.330

#### 4.240 BEARINGS AND BEARING SURFACES

- 4.240 SPACECRAFT LUBRICATION  
J. F. Judge, Published in Missiles and Rockets, May 13, 1963,  
p. 27 and 30.

Includes the status of liquid metal lubrication research directed towards space power conversion systems. (Hg, K, Rb, and Li).

- 4.240 DETERMINATION OF WORKING FLUID LUBRICATION CAPABILITY IN JOURNAL BEARINGS  
Quarterly Progress Report. 15 Sept. 1962. Rocketdyne, Canoga Park, Calif. Contract AF 33(616)-8328 (BPSN No. 6L-6199-3044-304402) R-3159-2.

Performance of K lubricated journal bearing test system used water lubricated tests to predict performance. Maximum temperature reached 1000°F at 35,190 rpm and a load of 27.0 lb. Test bearing material: tungsten carbide (Carboloy 883); test bearing shaft material: Mo-0.5Ti with tungsten carbide coating (LW-1). Results: found that the coating failed badly with a material transfer from the shaft to the carboloy bearing. The goal of contract: to obtain data on a 1 in. diameter journal bearing operating at 36000 rpm with 100 lb load using K or Rb as the lubricant at 1200°F for 1500 hours operation.

- 4.240 Determination of Working Fluid Lubrication Capability in Journal Bearings Hall, J., Sept. 61 96p.  
AD-264 785 (Contract AF 33(616)8328; Proj. 1(2-3044)) Rept. no. R-3159.

Studies were initiated on Journal bearings lubricated by the liquid alkali metals K, and Rb in a 1500-hr endurance run on each fluid. Installation and checkout of most of the K bearing experimental equipment was completed. The K supply loop is in operation and has accumulated over 100 hr of running time. Temperatures of 1235 F were achieved. The general-purpose bearing test rig has been successfully operated with water. The endurance test rig has been fabricated.

- 4.240 Research on Liquid Metals and Other Unusual Materials (Sundstrand)  
J. R. May, NASA TN-D-769, 1960

K & Hg as bearing lubricants. NSA 15:13283

#### 4.300 SODIUM LOOP DESIGN

- 4.300 AEC-TR-5310  
PRELIMINARY DESIGN FOR A TEST-COMPONENT LOOP WITH LIQUID SODIUM  
AT ELEVATED TEMPERATURE  
Colombo, P. (Italy, Comitato Nazionale per l'Energia Nucleare.  
Laboratorio Ingegneria e Servomeccanismi Reattori, Ispra.) Trans-  
lated for Oak Ridge National Lab., Tenn. 1962. 12p.

The liquid sodium loop and its principal components are described. The loop will permit operating experience to be acquired on liquid metal systems, particularly with regard to their manipulation and control of oxide content, and will furnish principles for the evaluation of the behavior of the components and the instrumentation. The loop (with a maximum temperature of 770°C) essentially consists of a hot section supplied by a 50 kw resistance heater and a cold section in which the heat supplied by the heater in the loop contains two dismountable test sections for evaluating components in liquid sodium. The system will be connected to a sodium melting furnace and will be equipped with an auxiliary inert gas system (argon or helium). (N.W.R.)

- 4.300 CONSTRUCTION AND OPERATION OF A SODIUM CIRCULATION (SYSTEM)  
Lutz, Otto and Rex, Dietrich  
(Technische Hochschule, Braunschweig, Ger.)  
VDI Zeitschrift, 104:581-7 (1962) (In German)

A test plant was built which made it possible to circulate liquid sodium in a closed circuit and to study the behavior of containment materials which occur in sodium-cooled reactors. The development of the sodium circulation system required special consideration and constructive solutions regarding heat transfer, the sealing of the plant, an oxide-free circulation, fire prevention, electric control, charging with sodium, and startup of the plant. Sodium fire fighting methods are described. (auth)

- 4.300 AEC Sodium Components Development Program (NASA-AEC Liquid  
Metal Corrosion Meeting, Dec. 1961 at BNL)

A survey of past, present, and future with listed references  
TID-7626 (Part 1) (AGN Lib. 2-2786)

- 4.300 Effect of 1200 F Sodium on Austenitic and Ferritic Steels  
Bi-Monthly Progress Report No. 1 for July and August 1959 on  
Thermal Shock, Nitriding, Stressed Corrosion, Unstressed Corrosion  
Mausteller, J. W. and Werner, R. C.  
MSA Research Corp., Callery, Pa.  
MSAR 59-99, Sept. 16, 1959, 22 p. Contract AT(11-1)-765

Completion of preliminary designs for a thermal shock loop, a corrosion loop, and a nitriding loop is reported. Stresses and unstressed corrosion studies are scheduled to be carried out in the same system. A literature search was started, and various sites were contacted to avoid duplication of effort. It was found that some work has been done at 1200 F sodium temperature with various oxygen concentrations, however, part of the data is not consistent. Test plans include corrosion testing of Croloy and stainless steel samples as well as similar and dissimilar welds of these materials in 1200 F sodium.

NSA 14:2695

- 4.300     2000 KILOWATT SODIUM TEST FACILITY  
           Whinery, L. A.  
           Contract W-7405-ENG-36. 119p (LAMS-2541)

The design and construction work completed on the 200-kw Sodium Test Facility during the period from April 1958 to Oct. 1959 is described. The purpose of the facility project is to test models of equipment components which are to be used in a molten plutonium, sodium-cooled fast reactor.

NSA 15: 24527

- 4.300             CENC-1038  
           Combustion Engineering, Inc. Nuclear Components Engineering  
           Dept. , Chattanooga,  
           SODIUM COMPONENT STUDY. Feb. 1959. 292p. Contract AT(11-1)-665.  
           \$45.00(ph), \$11.10(mf)OTS.

A design study is presented of a heat exchanger system to produce superheated steam from a source of heated radioactive Na. The purpose of the study was to produce a conceptual design of a less expensive and more reliable heat exchanger and steam generator of advanced design and improved performance for use in sodium-cooled reactor systems. The study was based on a 70-Mwh steam generator and a 70 Mw heat exchanger. Superheated steam at 1050°F and 2300 psig will be produced from 600°F feedwater. The heat source will be radioactive Na cooled from 1200 to 700-900°F. (T.R.H.)

- 4.300     A/CONF. 15/P/2291  
           Smith, F. A.  
           Argonne National Laboratory, Lemont, Illinois  
           Sodium Technology for Nuclear Power Plants. 30p.

Prepared for the Second U. N. International Conference on the Peaceful Uses of Atomic Energy, 1958.

Sodium-cooled power reactors will require sodium flow rates through the reactor of 10,000 to 50,000 gpm at pressures up to 100 psi and temperatures up to 1,000 degrees F. The present sodium-cooled reactors are smaller than required for central power plants; however, a program including development of pumps and piping systems, sodium pre-heating methods, instrumentation, heat exchangers, mechanisms and seals, and sodium chemistry has been instituted. A large composite test facility duplicating the salient features of the EBR-II primary sodium reactor system and containing 5,000 gallons of sodium has been in operation since 1955. Further work has been done on sodium purification for higher temperature systems, permitting the use of oxygen sensitive materials. A broad program of investigation has been initiated in the field of heat exchanger design, and several large sodium cooled reactors are under construction which will contribute extensively to the technology of sodium.

NSA 12:15105

- 4.300     COMPONENTS OF THE FUSED-SALT AND SODIUM CIRCUITS OF THE AIRCRAFT  
           REACTOR EXPERIMENT  
           Savage, H. W. et al.  
           ORNL-2348, Sept. 18, 1958; 43 p.

The Aircraft Reactor Experiment (ARE) successfully demonstrated the feasibility of generating heat by fission in a fused-fluoride circulating fuel. Most of the heat was removed from the reactor by the fused fluoride at 1580 degrees F. Sodium at 1350 F was used to cool the BeO moderator. With minor exceptions all the components proved to be adequate. The development of compounds and fabrication techniques for this reactor consumed a four-year period, during which time the technology of handling high-temperature fluids was extended to equipment operable above 1500 F. The methods used for determining compatibility of materials under static and dynamic conditions, standards for materials, and techniques for welding, fabrication, and assembly and the design criteria for pumps, seals, valves, heat exchangers cold traps, expansion tanks, instrumentation, preheating devices, insulation, etc., are described.

NSA 12:16694

- 4.300 COMPONENTS - HIGH PURITY SODIUM SYSTEMS  
J. E. Kemme (LASL) p. 229-33 of Proceedings of the 1957 Fast  
Reactor Information Meeting held at Chicago, Ill., Nov. 20-21, 1957

A series of small, pumped, sodium loops was used to study the problems peculiar to a LAMPRE-type reactor. The ultimate purpose of these experiments is to discover a means of purifying sodium. A description and results of the tests are given.

NSA 13:16600

- 4.300 KAPL-M-FJM-1  
SUMMARY OF DUPLEX TUBE ANALYSES. F. J. Mehringer. Sept. 28, 1956.  
Includes Appendices A through G. 73p.

The heat transfer characteristics and stress levels in duplex tubes for heat exchangers are interdependent. The various studies of the heat transfer characteristics and stress analyses are summarized. The heat transfer characteristics discussed are those for boiling water, liquid metal, and metal-to-metal contact. Analyses have been made of the fabricating and operating stresses. As a result of these various analyses recommendations were made regarding material properties, tolerances and surface conditions of the tubular components, fabricating procedures, and operating precautions. Where areas of uncertainty still exist tests have been recommended. This information is significant to the SIG Test Steam Generator Program, since this steam generator is to have duplex heat exchanger tubes.

- 4.300 KAPL-M-EDL-107 (Part 1)  
Hot Sodium Test of the S2G Rotating Plugs Part I. Program  
Report. Oscar D. Terrell. Nov. 28, 1955. 56p.

Planning, execution and results of the test program are summarized. The test results were satisfactory in that the Rotating Plugs met all the design specifications, also, the required tests were completed ahead of schedule. Detailed results were obtained from leak test, frozen sodium seal pressure tests, pressure drop tests of water cooling coils, rupture test of the frozen sodium seal with no cooling water, melting of the sodium seal with shield oil removed (the regular operating procedure) and with shield oil left in (special procedure), refueling conditions test with no cooling water, mechanical tests, jacking and rotating the rotating plugs, and additional information as acquired throughout the program.

- 4.300 APDA - 102  
INFORMATION REPORT BY ATOMIC POWER DEVELOPMENT ASSOCIATES COVERING  
WORK FOR THE PERIOD AUGUST 1, 1954 TO JANUARY 31, 1955. Jan. 31,  
1955. Dec1. Jan. 1, 1957. 82p.

Five group diffusion theory equations were used in calculations performed to assist in selection of a fast breeder reactor engineering design, and results are tabulated. The prolonged operation of a piston-type Johnson valve in Na was studied. Progress is reported on fuel element design and development. Analyses of the thermal performance of the elements were made. A cross sectional view of the reactor vessel design is given. The coolant flow characteristics through the reactor core during scram conditions are studied and typical scram histories are shown. A diagram of the liquid and steam-power systems is given. The intermediate heat exchanger is also shown. Diagrams of the once-through-type steam generator and the reactor and steam plant elevation are also shown. A facility for NaK-water reaction tests has been designed. Diagrams of the boiler test facility, the once-through-type test boiler and thermocouple locations for the proposed steam generator unit are shown. The design of the full-scale reactor and Na loop test facility is also discussed.

- 4.300 TID-7525  
Atomics International Div., North American Aviation, Inc., Canoga  
Park, Calif. Proceedings of the SRE-OMRE Forum Held at Los Angeles,  
California, Nov. 8 & 9, 1956. January 15, 1957. 313p. NAA-SR-1804

Papers on the Sodium Reactor Experiment include discussions of the design, physical progress, operations, component development and fabrication, fuel materials, and zirconium problems. Papers on the Organic Moderated Reactor Experiment include discussions of the design, construction progress, research and economics.

Nuclear Notes for Industry dated 4/26/57

- 4.300 NP - 5752  
SODIUM PLUGGING OF VENT LINES. E. C. King and V. K. Heckel.  
Sept. 7, 1955. 11p. Contracts N9onra-85801 and NObs-65426, Technical  
Report No. 42.

The distance sodium will travel in a copper or stainless steel pipe or tube of inside diameter between 0.180 to 0.622 in. can be calculated to within an accuracy of  $\pm 3$  ft from the equation:

$$S = (4 k_w d / k_w - 8.9 + 4 k_w d) (1020 d / 208 - T_a 18.08 d - 3059 / d - 0.1258)$$

where S is the distance of sodium travel in ft,  $k_w$  is the thermal conductivity of the tube wall in Btu/hr-sq ft- $^{\circ}$ F/ft, d is the inside diameter of tubing in in., and  $T_a$  is the ambient temperature in  $^{\circ}$ F surrounding the tube, or the tube wall temperature.

- 4.300 NP-5714  
Liquid Metal Technology. Final Report. (A review of the work  
from May 1949 to May 1954 with abstracts of reports issued).  
R. C. Werner. Mar. 29, 1955. 77 p. Contract N9onr-85801.

A final summary is presented of the various activities which have been carried out on liquid Na and NaK plumbing systems. Results on heat transfer, flow properties, corrosion tests, accessibility, Na cleaning, and tests on valves, bellows, pumps, etc. are included. Approximately half the report consists of abstracts of the various technical reports and memos which have been issued under the contract. (For preceding progress report see NP-5601.)

- 4.300 AN-5345 (Del. 2)  
REACTOR ENGINEERING DIVISION QUARTERLY REPORT FOR PERIOD JULY 1, 1954  
THROUGH SEPTEMBER 30, 1954. Oct 15, 1954. Decl. with deletions  
Mar. 29, 1957. 127p.

Reactor Programs. The design of the Boiling Experimental Reactor is described. The Borax-I reactor was intentionally destroyed by suddenly adding 4% excess reactivity. Design of the Borax-II reactor is described. It will be used for studies of transient behavior and steady-state operation as a steam producer. A preliminary design configuration has been established in EBR-II employing central, inner, and outer blankets. Fuel geometries including a smaller pin-type element are being investigated. Supporting Design, Research, and Development. The accuracy of diffusion theory for fast reactors was investigated. Water corrosion tests have been performed on high-U alloys, Zr- and Ti-base alloys, and Ni-plated Al plates. Thermal cycling tests were performed on fuel rods and pin-type fuel elements. Results are reported on tests on a current conductor connection for a high-temperature d-c electromagnetic pump, on Na valves with conventional packing, and on a rod-gripper test facility for the EBR-II. A vacuum cup sampler for high-temperature Na and NaK systems is described. Lifting and loading mechanisms for the EBR-II working model are described.

- 4.300 See Also: 2.330, 5.120, 5.230, 5.300, and 6.500.

- 4.300 ORNL-1688  
Oak Ridge National Lab.  
SODIUM PLUMBING. A REVIEW OF THE UNCLASSIFIED RESEARCH AND TECHNOLOGY INVOLVING SODIUM AT THE OAK RIDGE NATIONAL LABORATORY. William B. Cottrell and Leland A. Mann. Aug. 14, 1953. 82p. Contract W-7405-eng-26.

The research data and the development experience relevant to sodium obtained during the period 1950 to 1953 at the Oak Ridge National Lab. are summarized. Methods for testing the corrosion resistance of structural metals in sodium and the results of such tests are presented. The developmental work that has been done on the various components of sodium systems is described, and the relative merits of commercially available components are discussed. Cleaning, assembly, leak testing, and operating techniques and precautions are given. (auth)

NSA 8:2824

- 4.300 NP - 5872  
REPORT NO. 1 on 1000 KW SYSTEM. Memorandum Report No. 49.  
R. A. Tidball, F. L. Mangold, and S. N. Tower. Oct. 15, 1953. 14p.

The 1000-kw heat transfer system was designed to test pilot plant size liquid metal system components at temperatures to 1400°F. The test program was divided into phases: transferring heat to air and transferring heat to boiling water. Two liquid metal systems to prevent exposing the tubes of the liquid metal heater to full steam pressure in event of a failure of the steam generating equipment were used. The air cooled system is shown schematically. The NaK was circulated by a rotary magnet pump, through a flow meter into the NaK heater. The discharge from the heater was piped to the tube side of the intermediate heat exchanger, and returned to the pump. Sodium was circulated by a DC conduction pump, through the flow meter, the shell side of the intermediate heat exchanger, a swing check valve to the sodium cooler. Discharge of the sodium cooler passed through a stop valve, an a-c conduction pump to the suction of the d-c pump. The sodium was cooled by an air blast over finned tubes. Both NaK and sodium systems were fitted with diffusion type cold traps, expansion tanks, and emergency dump tanks. The sodium piping was fitted with tubular heaters (strapped to the outer surface) to preheat the piping before charging. Tests of the major components of this unit at various loads and temperatures are reported.

---

#### 4.310 CORROSION DEPENDENCE ON SYSTEM CONFIGURATION

- 4.310 AD258462 (ATIC WADD) Translation Liquid Metal Coolants in Nuclear Reactors

Information (based on foreign sources) on properties of liquid metals used as coolants in reactors is presented. Topics include: 1) heat transfer 2) interaction of liquid metals with structural materials 3) methods for removing impurities from liquid metals 4) peculiarities of design and operation ....

- 4.310 CENC-1038  
SODIUM COMPONENT STUDY  
Combustion Engineering, Inc. Nuclear Components Engineering Dept., Chattanooga, Tenn.

A design study is presented of a heat exchanger system to produce superheated steam from a source of heated, radioactive Na.

- 4.310 AD 256 511  
DESIGN, FABRICATION AND PERFORMANCE OF THE DUPLEX HEAT TRANSFER TUBE  
Mehring, R. J.  
(Knolls Atomic Power Lab., Schenectady, N. Y.) KAPL-1797, 60 p.  
(Sept. 28, 1956. Decl. Apr. 4, 1958)

The heat transfer characteristics and stress levels in duplex tube for heat exchangers are interdependent. This summary assembles into a single report the various studies of the heat transfer characteristics and stress analyses that have been made. The heat transfer characteristics discussed are those for boiling water, liquid metal, and metal-in-metal contact. Analyses have also been made of the fabrication and operating stresses. As a result, recommendations have been made regarding material properties, tolerances, and surface conditions of the tubular components, fabricating procedures, and operating precautions. Where areas of uncertainty still exist, tests have been recommended. This information is significant to the SIG Test Steam Generator Program, since this steam generator is to have duplex heat exchanger tubes.

- 4.311 EFFECTS OF EXPOSURE OF AUSTENITIC AND FERRITIC STEELS IN SODIUM MASS TRANSFER TEST LOOPS\*, R. S. Young, T. Lauritzen, E. G. Brush, GE-APED, 12<sup>th</sup> Annual AEC Corrosion Symposium, May 20-22, 1963, Castlewood, Pleasanton, California

Continuation of a program at General Electric, APED, under AEC contract has provided the opportunity for extensive examinations of steel samples exposed to flowing sodium in six test loops. 316 stainless steel, 2½Cr-1Mo and 5Cr-½Mo-½Ti steel test samples were exposed at temperatures between 600°F and 1200°F, also low and high oxygen sodium at various velocities were used. Loops are constructed of the three test materials to provide a series of mono-metallic and bi-metallic systems in order to obtain information relative to the use of these materials in sodium-cooled reactor systems.

Carburization of 316 stainless steel, decarburization of 2½Cr-1Mo steel, preferential movement of chromium and nickel with respect to iron, and austenite-to-ferrite transformation were noted. In general, with the exception of observed carbon changes, the weight changes observed in 316 stainless steel hot-leg systems (316 SS, 2½Cr-1Mo, or 5Cr-½Mo, - ½Ti cold-legs) are reflected by the measured changes in surface concentrations of the major alloying constituents. Measurements of changes in surface composition and concentration gradients of these constituents in 316 stainless steel by x-ray fluorescence and electron microprobe techniques confirm and chart the growth of metallographically visible surface ferrite layers.

The mass transport of carbon in the bi-metallic systems containing 2½Cr-1Mo steel cold legs is dependent primarily upon the availability of a carbon sink such as provided by the 316 stainless steel.

\* This work was performed under Contract USAEC AT(04-3)-189, P.A.#15. This paper presents information in extension of that presented in May 1962 on the same subject, Metallurgical Changes in Mono- and Bi-Metallic Sodium Mass Transfer Test Loops at the 11th Annual AEC Corrosion Symposium.

- 4.311 KAPL-1807  
Knolls Atomic Power Laboratory, Schenectady, N. Y.  
Solubility of Carbon in Sodium at Elevated Temperatures, by J. G. Gatton, June 30, 1957. 13p. Contract W-31-109-Eng -52.

An investigation was conducted to determine the solubility of carbon in sodium. This information was required to determine the difference in carburization of stainless steels between that caused by soluble carbon and that caused by suspended carbon. The data indicated that all carbon in amounts <5µ was, in fact, sodium-soluble carbon. The solubility of carbon in sodium under the experimental conditions varied from 32 to 74 ppm in the temperature range 147° to 700°C. The variation in the solubility, (S - ppm) of carbon with temperature may be expressed in  $S = 4.96 - 6.21 \times 10^{-2}/T$  at 0.003% oxide content, and as  $\ln S = 5.61 - 3.76 \times 10^{-2}/T$  at 0.026% oxide content.

NSA 12:2736

- 4.311 Material Transport in Sodium Systems by Haag, F. G. (General Electric Co., Schenectady, N. Y.)  
Chem. Eng. Progr. Symposium Ser. 53, No. 20, 43-50 (1957).

Data on the cause and magnitude of atom redistribution in flowing Na systems are summarized. System parameters are discussed, and  $O_2$  concentration and temperature are shown to be the significant variables. The radioactivity from the growth of radioactive structural isotopes in typical Na-cooled reactor systems is small.

CA 51:16011

- 4.311 KAPL-M-NGM-2  
Knolls Atomic Power Lab., Schenectady, N. Y.  
Distribution of Uranium and Uranium Oxide in Liquid Metal Thermal Convection Loops by Mills, N. G. and R. F. Loenig. Jan. 23, 1951.  
Decl. March 9, 1957. 12p. Contract W-31-109-Eng-52.

Two tests were performed in Na thermal convection loops to obtain on indication of (1) where U or  $UO_2$  would deposit in the SIR system in the event of a fuel pin failure and (2) how the dispersed fuel could be removed. It was also hoped that the results might apply as well to fission products since they appeared to accompany U in the experiment.

NSA 11:12564

- 4.312 To be expanded in the supplement.

- 4.313 To be expanded in the supplement.

- 4.314 LIQUID METAL CAVITATION PROBLEMS AND DESIRED RESEARCH  
Hammit, Frederick G., American Society of Mechanical Engineers,  
Paper No. 60-HYD-13, 1960, 7 p.  
Rev. of Met. Lit. 17:5

Cavitation of liquid Na, K, Rb, Na-K alloys, Hg, Bi and Pb-Bi alloys as heat-engine fluids versus  $H_2O$ . Temperature, density of liquid, density of vapor, viscosity, surface tension, heat capacity latent heat, thermal conductivity, vapor pressure and bulk modulus. (R2m, 14-60, Hg, Na, Na-b, Bi, Pb-b).

- 4.314 SELECTION OF LIQUID-METAL PUMPS. F. G. Hammit  
(Univ. of Michigan, Ann Arbor) Chem. Eng. Progr. 53,  
249-53 (1957).

The design and development of large-scale, liquid-metal circulating pumps such as would be suited to application in nuclear power plants have been investigated. Fluid dynamic problems-cavitation and erosion damage to the structural components at the high relative velocities obtained in the pump impeller - were the particular concern.

CA 51:10139

- 4.314 AECU-3777 Uncl.  
Nuclear Development Corporation of America, White Plains, New York.  
THE SODIUM-COOLED,  $D_2O$ -MODERATED REACTOR (SDR). Status Report.  
K. Goldmann and C. K. Leeper. (1958). 18p. (SDR-645)

...stainless steel, Zr, and Al subjected to hot Na jets ...

NSA 12:13443



#### 4.320 WELD STRUCTURE, BRAZEMENTS, AND CONNECTIONS

##### 4.320 DEVELOPMENT OF OXIDATION - AND LIQUID - SODIUM-RESISTANT BRAZING ALLOYS

D. Canonico and H. Schwartzbart (Lehigh Univ., Bethlehem, Penn. and Illinois Inst. of Tech., Chicago) Welding J. (N.Y.) 39, 122-8-S (1960) March.

A program is reported which had as its objective the development of filler alloys for brazing 310 stainless steel to Inconel at temperatures between 1750° and 1900°F, the joints to be resistant to oxidation and attack by molten Na at 1650°F . . .

NSA 14:9810

- 4.320 WADC-TR-57-648  
Illinois Inst. of Tech., Chicago, Armour Research Foundation.  
Development of Oxidation and Liquid Sodium Resistant Brazing Alloys by Domenic A. Canonico and Harry Schwartzbart, Sept. 13, 1957. 47p. Project title: Materials for P&W Subsystems.  
Task title: P and W ANP Materials. Contract AF33(600)-33400.

The first year's work has been completed at Armour Research Foundation on a program which has as its objectives: (1) the development of filler metals for brazing type 310 stainless steel to Inconel, the brazement to be resistant to oxidation and attack of molten sodium at 1650 F, and (2) the development of a simple test for the ductility of a brazed joint. Three metals - iron, chromium, and nickel - were selected, from oxidation and sodium resistance considerations, as the base metals from which to develop acceptable brazing alloys. From a study of all the available pertinent phase diagrams 91 alloys were devised, of which 16 satisfied the flow temperature and flowability requirements of the program. The flow temperature was between 1750 and 1900°F. Minimum flowability was three inches of length along a six-inch T-specimen. T-specimens brazed with these 16 alloys were subjected to an oxidizing atmosphere for 500 hours at 1650°F. Four alloys successfully withstood oxidation to a depth of less than 0.003 inch. A test for ductility of brazed joints, based on the premise that the load necessary to cause cracking in the fillet of a braze is a measure of the ductility of the brazing alloy, has been developed. The test has shown itself to be capable of differentiating two filler alloys, although the large amount of scatter obtained required that a statistical analysis of the data be applied. Further development should reduce the scatter.

NSA 12: 4842

- 4.320 Sodium Corrosion and Oxidation Resistance of High-Temperature Brazing Alloys. Slaughter, G. M. et al (Oak Ridge National Lab., Tenn.) Welding J. (N.Y.) 36, 217s-25s (1957) May.

Many of the brazing alloys which were investigated possessed excellent resistance to sodium corrosion and oxidation. Alloy systems of the Ni-Si-B, Ni-Cr-Si-B, Ni-Cr-Si-B, and Ni-Cr-Si types were found to be compatible in both media. Precious-metal alloys were, in general, severely attacked by sodium, as were many of the silicon-free, chromium-free, phosphorus-bearing alloys. Alloys containing manganese, tin or copper exhibited poor resistance to oxidation at 1500°F. In most cases, oxidation was more pronounced at 1700°F.

NSA 11:7189

- 4.320 Results of Static Corrosion Tests on Various Nickel-Base Brazing Alloys Used to Fabricate 304 Stainless Steel T-Joints. Joints Tested in Sodium and Fluoride #44(NaF-ZrF<sub>4</sub>-UF<sub>4</sub>) For 100 Hours at 1500°F. E. E. Hoffman. Dec. 3, 1954. Dec1. June 8, 1959. 3p. (CF-54-12-26) \$1.80(ph), \$1.80(mf) OTS.

NSA 13:22387

- 4.320 ORNL-1934  
AN EVALUATION OF CORROSION AND OXIDATION RESISTANCE  
OF HIGH TEMPERATURE BRAZING ALLOYS  
E. E. Hoffman, P. Patriarch et al., Oak Ridge

Many of the brazing alloys which were investigated were highly promising for Na-to-air service. Alloy systems of Ni-Si-B, Ni-Cr-Si-B and Ni-Cr-Si\* were especially favorable. Precious metal alloys were in general severely attacked by Na as were many of the Si-free, Cr-free, P bearing alloys. Alloys containing Mo, Sn, or Cu exhibited poor resistance to oxidation at 1500°F. In most cases, oxidation was more pronounced at 1700°F.

\*There is a Microbrazing-130 with 10 Si 19Cr balance Ni (0.1C) solidus liquid 1975, 2175 - 2075°F recorded temperature.

CA 55:16372f

- 4.320 NP-6202  
Illinois Inst. of Tech., Chicago. Armour Research Foundation.  
Development of Oxidation and Liquid Sodium Resistant Brazing  
Alloys. Quarterly Report No. 2 from October 14, 1956 to Jan. 15, 1957. Canonico, Domenic A. and Harry Schwartzbart. Feb. 5, 1957. 21p. ARF Project No. B-110. Contract AF33(600)-33406.

A program is being conducted by ARF to develop oxidation and liquid Na resistant brazing alloys and a simple ductility test for brazed joints. Three metals, Fe, Cr, and Ni, were selected from oxidation and Na resistance considerations, as the base metals from which to develop acceptable brazing alloys. From a study of all the available phase diagrams, fifty-five alloys have been selected for initial evaluation. Thirty-one alloys have been prepared and examined for melting points between 1700 and 1900°F. Six alloys melted within this range; a seventh had a melting point below 1700°F. All seven alloys were used to braze six-in. long T-specimens. Two alloys had sufficient flow ability (3 in.) to be acceptable. These alloys are 45.5 Ni-54.4 In and 40% Ni-30% Cr-30% Ge. A test for the ductility of brazed joints, based on the premise that the load necessary to cause cracking in the fillet of a braze is a measure of the ductility of the brazing alloy, has been studied. To date, the test has not yielded sufficient experimental reproducibility.

NSA 11:4460

- 4.320 NP-6292  
Illinois Inst. of Tech., Chicago, Armour Research Foundation.  
Development of Oxidation and Liquid Sodium Resistant Brazing  
Alloys. Quarterly Report No. 3 for January 15, 1957 to April 15, 1957. by Canonico, Domenic A. and Harry Schwartzbart. April 22, 1957. 9p. ARF Project No. B-110. Contract AF33(600)-33406.

A program is in progress at Armour Research Foundation which has as its objectives: the development of filler metals for brazing stainless steel to Inconel, the brazements to be resistant to oxidation and attack by molten sodium at 1650°F, and the development of a simple test for the ductility of a brazement. Atmospheric difficulties have been encountered during the brazing of T-specimens. A titanium sponge furnace has been added to the purification train in an attempt to eliminate this problem. Approximate melting temperatures have been obtained for 50 out of the 55 alloys originally proposed. Twelve alloys melted below 1900°F. Fifteen additional alloys have been prepared and are under study. These new alloys have as their base four alloys previously studied that had melting points above the maximum permissible temperature. Indium and/or silicon have been added as temperature depressants.

NSA 11:7196

4.320

ORNL-1934

An Evaluation of the Corrosion and Oxidation Resistance of High-Temperature Brazing Alloys. E. E. Hoffman et al., Nov. 7, 1956. Decl. Oct. 9, 1959. 40p. Contract W-7405-eng-26- OTS.

In evaluating the corrosion and the oxidation resistances of a brazing alloy for a specific application, emphasis was placed on the see-saw-corrosion and cyclic-oxidation studies. The Ni-Cr-Si alloy was compatible with sodium.

NSA 14:1804

4.320

NP-5840

Progress Report No. 31 for October and November 1955. W. J. Posey, ed. Dec. 12, 1955. 72p. Contract NObs-65426.

Testing of the 3-Mw steam generators was continued. Level indicators for liquid Na, combined valve connect and disconnect, and AC induction pumps for liquid metals are described. Microfissure propagation has been observed as a result of quenching heated weld specimens with liquid Na. The feasibility of using impure N<sub>2</sub> as a cover gas for sodium systems was demonstrated. Investigations were continued on the corrosion of Zr by liquid Na, the removal of Hg from sodium systems by amalgamation with Cu, and the radiation hazards arising from leaks in liquid metal systems.

4.320

KAPL-197

Knolls Atomic Power Lab., Schenectady, N. Y. Report on Sodium Resistant Brazing Alloys. Frandsen, J. P. and R. S. Zeno. June 30, 1949. Decl. Aug. 26, 1952. 17p. Contract W-31-109-eng-52.

An investigation was made on the effect of Na corrosion on the mechanical properties of brazed Type 347 stainless steel. Brazes of Ni-Mn, period of two weeks. It was found that none of the brazes were attacked by Na. On the basis of shear strength alone the Ni-Mn braze was found preferable, followed by Ni-Mo, Fe-P, and Ni-P in that order.

NSA 10:8876

4.320

ORNL - 1033

Quarterly Progress Report For Period Ending April 30, 1951  
E. C. Miller and W. H. Bridges, eds.  
Oct. 23, 1951. Decl. October 9, 1959  
82 p. Contract W-7405-Eng-26. OTS.  
Oak Ridge National Lab., Tenn.

The thermal cycling of thorium and uranium in Na-K has shown no real deformation of the thorium, but oxide scale formation with significant penetration did occur. The static corrosion testing of construction materials in a liquid-metal environment has continued. Work has started on the corrosion testing of various materials exposed to fused salts. Dynamic corrosion testing using thermal convection loops containing sodium, lead, and lithium is being carried on jointly with the Experimental Engineering Section of the ANP Division. Stainless Steel types 347, 321, and 310; Inconel; and Haynes Alloy 25 displayed very little attack by sodium in 1000 hr at 1500°C. The welds are still the vulnerable areas, and various welding techniques need investigation to determine the best way to eliminate this source of failure.

NSA 14:2671

4.321

TORQUE TUBE SEAL-OIC FLOW CONTROLLER

D. J. Hovley, (Atomics International, Div. of North American Aviation, Inc., Canoga Park, Calif.) May 8, 1961, 6 p.  
(NAA-SR-Memo-6374)

A torque tube seal for a sodium flow control is tested by being cycled 1000 times each at temperatures of 1000 and 1200°F in a flowing sodium system at a pressure of 100 psig. The tests are conducted in a test loop of the Hallam Power Reactor. No indication of leakage through the seal is noted under the test conditions. (T.F.H.)

NSA 15:24945

- 4.321 POWER LOSS AND INITIAL SHAFT TORQUE IN SEALS OF FROZEN SODIUM  
A. V. Dorbyshev and N. M. Turchin  
Atomnaya Energ., 10:386-7 (April 1961) (In Russian)

The friction power loss of frozen Na seals was analyzed as a function of the number of shaft rotations. The power loss in frozen sodium seals is 0.7 to 1% of the power used in Na pumping. The rate of sodium loss is 2 to 3 cm<sup>3</sup>/day. Considering laminar flow and pressure, the evaluated liquid Na film is 15 to 20  $\mu$ . The temperature distribution at a condensation point at various cooling temperatures is plotted as well as the tangential intensity  $\tau$  of the initial shaft rotation moment as function of temperature. (R.V.J.)

NSA 15:27721

- 4.321 A Combination Strainer and Blocking Valve for Liquid Metal Systems  
Nayor, F. S. and McDonald, J. S.  
Atomics International, Div. of North American Aviation, Inc.  
Canoga Park, Calif.  
NAA-SR-5241, 30 August 1960, 20 p. Contract AT-11-1-GEN-8

A 3-in. pipe-size combination valve and strainer device performed satisfactorily when tested in a sodium system. The device provided a means of removing an in-line strainer element from the system without draining the sodium and alternately served as a plug type blocking valve. Tests were conducted over a temperature range of 500 to 950 F and system pressures of 0.5, and 10 psi at NaO contents of 50 to 400 ppm. The strainer element was isolated from the system by freezing the sodium around the valve plug. The time required to freeze the sodium was found to be primarily a function of system temperature, a typical value being 75 min for a system temperature of 800 F.

NSA 14:22970

- 4.321 Valve Stem Freeze Seal for High-Temperature Sodium  
McDonald, J. S.  
Atomic International, Div. of North American Aviation, Inc.  
Canoga Park, Calif.  
NAA-SR-4869 July 30, 1960, 37 p. Contract AT-11-1-GEN-8

Valve stem freeze seals for high-temperature service in advanced sodium-cooled reactor systems were studied. An experimental model, suitable for use with a 6-in. size valve, operated satisfactorily under a variety of conditions. The freeze seal region was cooled by natural convection to ambient atmosphere; cooling by both circumferential and longitudinal finned sections was experimentally studied. The operating conditions included sodium bulk temperatures up to 1300 F, sodium pressures up to 75 psig, and ambient temperatures as high as 150 F. Anti-convection rings were positioned in the sodium-filled annular between stem and stemguide, and the effects of their presence was studied. Predictions of temperature profiles along the stem, using several different analytical methods, were compared with experimental results.

NSA 14:21079

- 4.321 Performance Test of a Two-Coolant-Region Sodium Pump Shaft Freeze-Seal. F. O. Streck. July 15, 1959. 15p.  
(NAA-SR-Memo-4119) \$3.30(ph), \$2.40(mf) OTS.  
NSA 13:23110

- 4.321 A Gas Shaft Seal for the HNPF Sodium Pump  
Admire, B. W. and Nayor, F. S.  
Atomics International, Div. of North American Aviation, Inc.,  
Canoga Park, California, NAA-SR-Memo-2616, 30 June 1958, 6p.

Lip type, oil labyrinth gas seals were tested for use on Hallam Power Reactor sodium pumps with a 5-in. diameter rotating shaft. The seals were not recommended for use owing to excess helium leakage and short life.

NSA:15:4081

- 4.321        NAA-SR-4204    Atomics International Div. North American  
Aviation, Inc., Canoga Park, Calif. Tests of a Mechanical Pipe  
Joint for Sodium Service, C. Sutherland, Jan. 15, 1960. 26 p.  
Contract AT-11-1GEN-8 OTS

A test program was conducted to determine the suitability of a mechanical pipe joint for use in liquid sodium systems. Tests were performed on a total of five units representing three pipe sizes -2-, 6-, and 12-in. The joints were subjected to flexural, axial, tensile, and compressive mechanical loads while containing sodium at a maximum temperature and pressure of 1000°F and 150 psig. Of the three sizes tested, only the 2-in. size performed satisfactorily. The other units leaked sodium during the mechanical load tests after having sealed 1000°F sodium under to-load conditions. It is concluded that the 2-in. units have a good probability of performing satisfactorily in elevated temperature sodium service with nominal adjacent pipe wall stresses up to a maximum of 14,000 psi. It is further concluded that the larger sizes tested will probably provide good high-temperature sodium seals, but their use must be restricted to service at very low stress levels. Tolerance limits were not established for flange warpage due to welding. It was found that the mechanical pipe joints tested will not seal under the test conditions if they become out-of-round as much as 10 mils. (auth)

- 4.321        Liquid Metal Seal for Sodium Pump Shafts  
Carniglia, S. C.  
Atomics International, Div. North American Aviation, Inc.,  
Canoga Park, Calif., NAA-SR-Memo-2184. October 4, 1957, 7p.

Several liquid metal sealants were investigated for sodium-pump shafts.

NSA 15:4080

- 4.321        Sodium Reactor Experiment Pump Development.    R. Cygan.  
Jan. 1, 1957. 37p. (NAA-SR-1662)

Operation of a 6 X 8 X 13 freeze seal type centrifugal pump has been carried out at Na temperatures up to 1200°F. Measurements have been made of cooling requirements, pressure drop, torque, temperature distribution, and reliability of the freeze seals employed in the pump. Design and operational techniques are described. This pump design appears promising for large-scale liquid-metal systems.

- 4.321        Freeze-Seal Valves and Pumps  
Cygan, R. and A. M. Stelle (North American Aviation, Inc.), Canoga  
Park, Calif. Chem. Eng. Progr. 52, 157-9 (1956). April

Freeze seals have been developed for sealing stationary and rotating shafts affording a simple means of adapting commercial equipment for use in high-temperature liquid-metal systems. Several designs for sealing sodium at temperatures up to 1200°F have been satisfactorily tested. Under different operating conditions cooling loads, torque, and temperature distribution were measured. Locating the freeze-seal away from the high-temperature region allows the formation of an annulus of frozen metal around the shaft with small cooling loads.

- 4.321        NP 7391  
Performance of a Frozen Sodium Seal on a 120 GPM Duriron  
Centrifugal Pump, Heckel, V. K. and King, E. C., Mine Safety  
Appliances Co., Callery, Pa., June 28, 1954, 15p, Contract NObs-  
65426,

Experimental data indicated that the flow and pressure of the centrifugal pump met the design capacity. The motor was found to be inadequate in that seal friction accounted for 40% of the input. The second test indicated that seal leakage during the operation was not excessive and the pump could not be started and stopped without raising the seal temperature.

NSA 13:12678

- 4.321 Design and Operation of Freeze-Seal Valves and Pumps.  
R. Cygan and A. M. Stelle AI CH. E. Journal 52 No. 4  
157 (1956)

Freeze seals developed for stationary and rotating shafts offer a simple means of adopting commercial equipment to high-temperature liquid metal systems. Several designs for sealing sodium at temperatures up to 1200°F have been satisfactorily tested, and under different operating conditions cooling loads, torque, and temperature distribution were measured. Locating the freeze seal away from the high-temperature region allows the formation of an annulus of frozen metal around the shaft with small cooling loads.

- 4.321 Hot Sodium Test of the S2G Rotating Plugs Part I. Program Report. Oscar D. Terrell. Nov. 28, 1955. 56p. (KAPL-M-EDL-107(Pt.1))

Planning, execution and results of the test program are summarized. The test results were satisfactory in that the Rotating Plugs met all the design specifications, also, the required tests were completed ahead of schedule. Detailed results were obtained from leak test, frozen sodium seal pressure tests, pressure drop tests of water cooling coils, rupture test of the frozen sodium seal with no cooling water, melting of the sodium seal with shield oil removed (the regular operating procedure) and with shield oil left in (special procedure), refueling conditions test with no cooling water, mechanical tests, jacking and rotating the rotating plugs, and additional information as acquired throughout the program.

- 4.321 SIG Rotating Plugs Test. R. A. Jacoby and A. P. Kokosa.  
Feb. 21, 1956. 159p. (KAPL-M-EDL-65).

The mechanical and heat transfer characteristics of the Mark A rotating plugs were investigated. The tests were conducted with static Na and without radioactivity. The results of the testing program indicated the desirability of improvement in the heat transfer characteristics and in sealing of the plugs. The need was also pointed up for improvement of the rotational characteristics that simulate the refueling operation of the rotating plugs. Developmental work was accomplished and the heat transfer, sealing, and rotational characteristics were improved.

- 4.321 S2G Valve Sodium Freeze Seal Evaluation. Phase II.  
P. K. Salzman and F. N. Schell. Nov. 20, 1956. 50p. (KAPL-M-EDL-124)

The design of the S2G 8-inch sodium stop valve freeze seal was evaluated under established conditions by cycling before and after a simulated bellows failure. The effectiveness of the freeze seal under severe ambient, water flow and insulation conditions was also evaluated. The stop valve operated successfully under all test conditions.

- 4.321 SIG Freeze Seal Test II. R. G. Jacoby and P. A. Benson.  
May 25, 1954. 31p. (KAPL-M-EDL-71)

Two arrangements of internal components of a freeze seal model were tested in order to determine the hydraulic characteristics. The internal configuration employing cylindrical knitted mesh packings in the connecting pipes proved the most suitable for the Na servicing freeze seal, because these packings are more easily fabricated.

- 4.321 Report 1 on Freeze Seal Performance. Memorandum Report 55.  
T. A. Ciarlariello and R. A. Tidball. May 4, 1954. 6p.  
(NP-7389) NSA 13:12676

- 4.321 KAPL-M-WMK-2  
Knolls Atomic Power Lab., Schenectady, N. Y.  
Pressure Rise in a Confined Volume of Molten Sodium Upon Addition of Heat Knox, W. M. May 20, 1953. 7p. Contract W-31-109-Eng-52

The effectiveness of a number of lubricants and treatments in reducing the tendency of stainless steel threads to gall during exposure to Na was determined, using the torque required to loosen bolted assemblies as the criterion. Of the methods tested, only nitriding and carburizing were successful. Additional tests will be made of other methods of preventing galling, which are based on thread contour and clearances.

NSA 11:2452

- 4.321 Sodium Vapor Transport in a Closed System. J. J. Kauzlarich.  
June 17, 1953. Decl. Mar. 12, 1957. 11p. (KAPL-M-JJK-1)

The transport of Na in a closed system is studied, and a Labyrinth-type vapor seal is investigated for possibilities of limiting Na vapor transport. Theory predicts that such a seal will be ineffective because it will collect Na vapor, the large cross section does not limit diffusion or evaporation, and the seal will not offer resistance to pressure surges.

- 4.321 KAPL-M-EGB-2  
Knolls Atomic Power Lab., Schenectady, N. Y.  
Determination of Anti-Galling Techniques for Austenitic Stainless Steels. Brush, E. G., May 15, 1952. 4p. Contract W-31-109-Eng-52.

In order to determine the effectiveness of an anti-galling compound, several one-inch stainless steel bolt-sleeve-nut assemblies were coated with platinum oxide, tightened to 250 lb-ft torque and immersed in sodium at 500°C for one month. The average loosening torque at the conclusion of the test was higher than that required for untreated bolts so that the compound was apparently of no benefit in reducing the tendency of Type 347 stainless bolts to gall.

NSA 10:10848

- 4.321 KAPL-M-PMC-1  
Knolls Atomic Power Lab., Schenectady, N.Y. Freeze Seals.  
Clark, P.M. July 14, 1952. 6p. Contract W-31-109-Eng-52.

Results are presented from tests on an air-cooled freeze seal suitable for use in the Submarine Thermal Reactor service lines. The seal consists of a finned pipe section for freezing the sodium and a trap for retaining sufficient sodium in the seal for freezing. The seal is considered a one way freeze seal because it will pass gas in one direction only without emptying the liquid from the seal. The test arrangement is illustrated and performance data are summarized.

NSA 10:10823

- 4.322 SODIUM CORROSION AND OXIDATION RESISTANCE OF HIGH-TEMPERATURE BRAZING ALLOYS  
Slaughter, G. M. et al (Oak Ridge National Lab., Tenn.)  
Welding J. (N.Y.) 36, 217s-25s (1957) May.

Many of the brazing alloys which were investigated possessed excellent resistance to sodium corrosion and oxidation. Alloy systems of the Ni-Si-B, Ni-Cr-Si-B, Ni-Cr-Si-B, and Ni-Cr-Si types were found to be compatible in both media. Precious-metal alloys were, in general, severely attacked by sodium, as were many of the silicon-free, chromium-free, phosphorus-bearing alloys. Alloys containing manganese, tin or copper exhibited poor resistance to oxidation at 1500°F. In most cases, oxidation was more pronounced at 1700°F.

NSA 11:7189

4.322 RESULTS OF STATIC CORROSION TESTS ON VARIOUS NICKEL-BASE BRAZING ALLOYS USED TO FABRICATE 304 STAINLESS STEEL T-JOINTS

Joints Tested in Sodium and Fluoride #44 (NaF-ZrF<sub>4</sub>-UF<sub>4</sub>) For 100 Hours at 1500°F. E. E. Hoffman. Dec. 3, 1954, Dec. 1. June 8, 1959. 3 p. (CF-54-12-26) \$1.80(ph), \$1.80(mf) OTS.

NSA 13:22387

4.330 FATIGUE OF EXPANSION/CONTRACTION COMPONENTS

4.330 PRELIMINARY STUDY OF THE FATIGUE OF METALS IN LIQUID METAL ENVIRONMENTS, J. W. Martin and G. C. Smith. Metallurgia 54, 227-32, 238(1956).

A series of expts. with 70/30 brass showed that amalgamation reduced the life at all stresses. The effect appears to be a min. in the region of the fatigue limit and increases rapidly as the stress amplitude is increased. In the amalgamated specimens, intergranular failure occurred over the whole of the fracture surface, although the zone wetted by Hg did not extend to the center of the fracture. In the case of 60/40 brass, specimens were fractured with and without Hg. In the fracture of an amalgamated specimen the path of the cracks tends to follow the  $\beta$ -matrix rather than run through the  $\alpha$ -phase, but in the nonamalgamated specimen the path of the fracture is random. The lower the fatigue stresses, the greater the depth of penetration of the Hg. Tests were run with mild steel in contact with liquid Sn and 18/8 stainless in contact with liquid Na. In the case of the mild steel, the fatigue limit is raised at elevated temp. and life is increased at stresses above the fatigue limit. In contact with liquid Sn, the fatigue limit is lowered and life at stresses above the fatigue limit is reduced. The proportional decrease in life is greatest at the higher stresses employed and least in the region of the fatigue limit. In the case of 18/8 stainless steel in contact with liquid Na, life does not seem significantly different from empty specimens, although a no. of cracks have been observed in specimens contg. Na. 11 references.

CA 51-998a

4.330 Investigation of Variables Affecting Bellows Life in Liquid Sodium McDonald, J. S.

Atomic International, Div. North American  
Aviation, Inc., Canoga Park, Calif.  
NAA-SR-Memo-2414, 27 January 1958  
NSA 15:4249

Bellows are used in valves and other components in sodium graphite reactors at and below 1000 F. A study was made of the variables which can affect the life of bellows in sodium systems. A study was also made to determine which variable can be investigated experimentally.

4.330 KAPL-M-JMG-7 Knolls Atomic Power Lab., Schenectady, N. Y.  
Examination of SlG Sodium Stop Valve Bellows. Gerken, J. M.  
Jan. 4, 1957. 9p. Contract W-31-109-Eng-52

Two 8-inch Na stop valve bellows were endurance tested and an evaluation was made of the bellows welds. Mass spectrometer leak testing of these bellows indicated that they were leak tight. A 2-inch Na stop valve bellows which leaked at a point on one of the outer welds was examined for the cause of leaking. The weld in the region of the leak was found to be severely oxidized internally, indicating that the flow of inert shielding gas failed momentarily during welding.

NSA 11-3554



- 4.330 AD 256511  
TRANSIENT THERMAL STRESSES IN THIN-WALLED CYLINDERS. SIR MECHANICAL  
ENGINEERING ANALYSIS  
Jahsman, W. E. (Knolls Atomic Power Lab., Schenectady, N.Y.)  
KAPL-M-WEJ-3, 41 p. (Oct. 1956)

Using experimental data showing the time behavior of temperatures at various depths in the thin wall of a cylindrical pipe whose exterior is insulated and whose interior is repeatedly thermally shocked by a liquid Na stream, it is possible to predict the surface temperature transient analytically by representing it by a series of straight lines. Once the transient temperature distribution across the wall thickness is known, the time at which the surface temp. deviates most from the mean wall temp. can be obtained. The temp. distribution at this time of maximum deviation has importance because it can be used to determine the maximum surface thermal stress. Plasticity theory is used for the stress calculation because results by elastic theory show that maximum thermal stresses exceed the yield strength of the pipe material, AISI 347 stainless steel. Transforming the thermal strains associated with the calculated stresses into equivalent uniaxial strains, it is found that the thermal shock test results do not contradict any of the existing strain fatigue data for the material.

- 4.330 RESULTS OF A KAPL THERMAL STRESS TEST ON A STAINLESS STEEL TUBE.  
R. W. Lockhart and R. G. Kennison. Dec. 15, 1949. Decl. Mar. 9, 1957.  
7p. (KAPL-M-RWL-5)

The effect of a repeating or cycling thermal stress on a thin wall stainless steel tube was determined. The apparatus used was essentially a paralleled flow single pass concentric tube heat exchanger with hot Na flowing through the inside of the inner tube and cold Na flowing in the annulus between the inner and outer tubes. It is concluded that the experimental values of Na film coefficients are about 35% lower than predicted but are of the right order of magnitude. A thermal stress varied from zero to 32,400 psi 132 times is insufficient to cause a crack or failure in a stainless steel tube at an average temperature of 540°F.

---

#### 4.340 BEARINGS AND BEARING SURFACES

- 4.340 FRICTION AND WEAR BEHAVIOR OF POSSIBLE BEARING MATERIALS IN  
HIGH PURITY LIQUID SODIUM AT TEMPERATURES UP TO 500°C  
Roberts, W. H. (United Kingdom Atomic Energy Authority,  
Risley, Lanes, Eng.) Preprint Paper No. 3. Engineers, 1962. 10p.

A crossed-cylinder apparatus is described which enables basic friction and wear data for materials immersed in liquid metals to be obtained. Results are presented for a selection of chromium alloys rubbed under boundary lubrication conditions in high-purity sodium in the temperature range 200° to 500°C. The behavior of these combinations is compared with that in gases (carbon dioxide and helium), under corresponding conditions of load, rubbing speed, and temperature. Friction coefficients and wear rates were generally lower in sodium, implying that the liquid metal provides a measure of lubrication between the rubbing surfaces. A striking feature of the results in sodium is the manner in which wear rate increased fairly regularly with increasing temperature for all the rubbing combinations examined. This behavior is in complete contrast to that in carbon dioxide and helium, where the wear-temperature curves varied markedly for different combinations. Experiments are described which were aimed at establishing that hydrodynamic lubrication did not materially contribute to the observed effects in sodium. (Author)

4.340

"Sliding Contact Frictional Behavior in Sodium Environment," by J. W. Kessel et al., Am. Soc. Lubric. Engrs. Trans. 5:39-44 (1962).

Wear and friction phenomena were studied for rubbing surfaces of Mo, dry and lubricated with Na at 80-1300°F., in vacuo and in Argon. In the presence of Ar, the coefficient of friction for dry Mo specimens increased from approximately 0.6 - 0.75 to 0.7 - 0.9 from 100-800°F., and then decreased to approximately 0.5 - 0.7 as temperature increased to 1200°F. Similar behavior was noted in vacuo. The coefficient of friction for Mo lubricated with Na remained nearly constant at approximately 0.35 at 300-1000°F after the specimen had been conditioned for 40 hours at  $3 \times 10^{-2}$  mm Hg pressure. After 60 hours at  $1 \times 10^{-5}$  mm, a similar specimen had a coefficient of friction which increased from approximately 0.1 to 0.4 as the temperature increased from 300 to 1200°F. Wear tracks indicated deep galling and plowing for dry Mo, but only superficial damage for a Na-lubricated Mo surface, probably due to the formation of  $\text{Na}_2\text{MoO}_4$ .

CA 57:10895c

4.340

STATIC SODIUM TEST OF WESTINGHOUSE FLOW CONTROLLER BEARING  
(NAA-SR-Memo-5951)

R. Cygan (Atomics International Div. of North American Aviation, Inc., Canoga Park, Calif.) Dec. 8, 1960. 7 p.

Tests were carried out to determine the action of a static Na environment on a special high-temperature ball bearing while operating at the specified speed and loading. The test bearing was operated at 85 rpm and 870 pounds axial load for 385 hr at 1000°F. Visual inspection of the test bearing showed a very marked increase in roughness of both the balls and the ball races. Details of the measure merits and a photograph of the bearing parts after tests are given. On the basis of this test it did not appear that this bearing will be satisfactory for the service intended. (M.C.G.)

NSA 15:19492

4.340

Behavior of Rubbing Molybdenum Surfaces in Sodium Environments

Kissel, John W., Melton, Carl W., Glaeser, William A.  
Battelle Memorial Institute, Columbus, Ohio  
U.S. Atomic Energy Commission BMI-1405, 23pp. (1960)

A study of Mo sliding against itself in liquid Na yields interesting evidence to support a reacted-surface film hypothesis for the mechanism of lubrication of Mo by liquid Na. Na influences the sliding behavior of Mo by modifying reacted films which provide boundary lubrication. These effects are temp. dependent. The sliding specimens consisted of a ball and a flat rectangle. Operating conditions were Na temps. of 250-1300°F., sliding speeds of 0.22 to 2.5 mm/sec, and contact stresses of 80,000 lb/sq in. The addn. of clean Na between dry Mo rubbing surfaces in an Ar atm. of high purity produces a marked drop in friction coeff. and the character of the wear scar changes from galling to superficial scratching. These effects persist after the removal of Na by evapn. Studies of the films were conducted by using electron and x-ray diffraction, electron microscope, and differential thermal analysis techniques. A film of  $\text{Na}_2\text{-MoO}_4$  on the Mo surfaces provides low friction and diminished surface damage. Examn. in vacuum up to  $10^{-6}$  mm. Hg demonstrates that the native oxides,  $\text{MoO}_3$  and  $\text{MoO}_2$ , also influence its sliding behavior.

CA 54:14038f

Lubrication Behavior of Liquid Metals, P. H. McDonald  
North Carolina St. College Raleigh. WADD TRE 9-764

The report describes the investigation of the lubricating behavior of liquid metals in 2 categories: hydrodynamic and boundary lubrication. The basic theory of hydrody. study is the Reynolds equation. This theory has been expanded after the manner of Christopherson to a new state of development. An experimental device has been designed and constructed for confirming theory as it relates to liquid metals. . . . . A macroscopic theory of boundary lattice region has been employed. This theory has been applied to a cylinder-flat combination, and the lubrication behavior has been seen to depend upon the state of contact stress for this configuration. Apparatus for this has been designed also.

4.340

EVALUATION OF MATERIAL WEAR AND SELF-WELDING IN SODIUM-COOLED REACTOR SYSTEMS

R. B. Jerman (Allis-Chalmers Mfgs. Co., Milwaukee) and  
R. C. Williams and D. O. Leeser (Atomic Power Development Associates, Inc., Detroit). J. Basic Eng. 81, 213-25 (1959) June.

Laboratory and prototype component tests were made to determine the degree of adhesion and self-welding of various bearing-couple materials in liquid Na. A few tests were run in N<sub>2</sub> and Ar. Temperatures were from 500 to 1000°F and the static loads on the bearing surfaces were up to 10,000 psi. The harder materials showed better wear resistance than did softer materials.  
(auth) NSA 13:16564

4.340

IGR-TN/W-862 UNCLASSIFIED

United Kingdom Atomic Energy Authority. Industrial Group H. Q ,  
Risley, Lancs, England.

The Adhesion of Niobium and Stainless Steel Surfaces During Irradiation in Sodium

Howd, D.

Apr. 10, 1958. 12 p.

Contacts consisting of stainless steel-niobium, stainless steel-stainless steel, and niobium-niobium were irradiated for 1280 hours in sodium at about 600°C under a load to give 800 psi at the interfaces. No signs of adhesion or pressure-welding were detected on subsequent examination.  
(auth)

4.340

KAPL-1079

The Performance of Tungsten Carbide Journal Bearings Operating In Liquid Metals. Vail, D. B. Jan. 25, 1954.  
Changed from Official Use Only June 26, 1956. 49p.  
Contract W-31-109-Eng-52.

The results of a series of tests indicated that liquid-metal-lubricated journal bearing performance may be predicted adequately by existing theoretical and empirical concepts. Test performance of the journal bearings was closely correlated with the theoretical performance postulated by Cameron and Wood for a full journal bearing. The calculated minimum film thicknesses were also shown to be as empirically postulated by Cameron. In the range of boundary lubrication it was observed that tungsten carbide ceramal bearings resisted the immediate seizure characteristics shown by other alloys, but that some roughening of the bearing surfaces occurred for the particular ceramals used in this series of tests.

NSA 11:2448

4.340

Resistance of Titanium Carbide Bearing Materials to Corrosion in Sodium. Brush, E. G., April 15, 1953. 6p.  
Contract W-31-109-Eng 52. Report No. 5 on Evaluation of the Behavior of Various Materials in Sodium (Problem No. 21)  
KAPL-M-EGB-14

The corrosion resistance of four titanium carbide ceramals was determined in Na at 500°C and was found to be of the same order of magnitude as Carboloy 55A and 779 (tungsten carbides).

NSA 10:10835

4.340

AERE-R/R-1891

Gt. Brit. Atomic Energy Research Establishment, Harwell, Berks, England. Some Preliminary Tests on Bearing Materials to Operate Under Liquid Sodium-Revised Interim Report. June 1954; D. F. Elliott et al. April 23, 1956; Decl. September 17, 1957; 37 pages.

The object of these tests is to determine the most suitable materials to be used in the construction of bearings for a 50 H.P. Sodium Pump. The most critical period of operation for these bearings is during start up, when a condition of 'boundary lubrication' will exist, and metal-to-metal contact will occur between the rotating shaft and the bearing until the speed of the pump shaft is sufficient to give true 'hydrodynamic lubrication' by creating a continuous film of sodium within the bearing. The characteristics required for a suitable pair of bearing materials are given. The results of these tests may also be useful in the selection of materials for use as rubbing surfaces in reactor mechanisms which are required to operate submerged in liquid Na or Na-K alloy.

NSA 12:3639

4.340

KAPL-M-HLT-1

Knolls Atomic Power Lab., Schenectady, N. Y.

Wear and Galling Tests of Plug Seal Tubing, Report No. 1

Brush, E. G. and H. L. Tymchyn. Feb. 25, 1954. 16 p.

Sub-Project No. 27, Contract W-31-109-Eng.-52.

To determine the effect of Cr plating on the wear and galling characteristics of the plug seal tubing laboratory tests simulating the sliding action of the rotating plug during raising and lowering operations have been completed in Na at 500°F. Cr plated and as drawn tubing sections, loaded to deflections of 15 and 30 mils, were drawn over plates representing the container wall under conditions simulating 355 plug raising and lowering operations. Results indicate that sizing due to galling is unlikely in SIR and that for deflections in the range of 0 to 20 mils as drawn tubing has satisfactory resistance to wear and scoring. Above 20 mil. deflections Cr plating will reduce the amount of scoring and wear experienced by both tubing and container wall.

NSA 10:10822

4.340

KAPL-M-EGB-16

Knolls Atomic Power Lab., Schenectady, N. Y.

Aluminum Bearing Alloys in Sodium. Report No. 2 on Evaluation of the Behavior of Aluminum in Sodium. Problem No. 28.

Brush, E. G., April 6, 1954. 15p. Contract W-31-109-Eng-52.

Simulated bearing tests have shown that certain Al base alloys have attractive bearing properties for service in Na and NaK. Previous corrosion tests have shown that the behaviour of Al in Na is greatly influenced by the presence of stainless steel. To study this influence under simulated bearing conditions, non-rotating sleeve and journal tests were run in Na at 300, 400 and 500°C. Additional tests were made to determine the solubility of Al in Na as a function of temperature. The tests reaffirm previous findings that at temperatures above 400°C, the high corrosion rate of Al base alloys prohibits their use in Na-stainless steel systems.

4.340

BNL-756

LIQUID METAL RESEARCH AT NASA-LEWIS RESEARCH CENTER

James P. Lewis, Lewis Research Center, Cleveland, Ohio

Second Annual High Temperature Liquid Metal Heat

Transfer Technology Meeting, BNL, May 17 and 18, 1952

The paper outlines the major liquid metals research and development efforts at Lewis Research Center. The work includes: a Two-Phase Sodium Loop for flashing sodium vapor; the Sodium Turbine Facility using refractory metals; Pump Test Facilities including one low pressure K pump and one high pressure Na pump; Alkali Metal Heat Transfer Facility using EM pumps and Cb-12r above 1500°F and type 316 stainless below; A Space Radiator and Condenser Facility using a NaK loop for boiling potassium; Bearing and Seal Studies using liquid Na environments; Mercury Programs relative to the radiator problem in zero gravity similar to SNAP VIII conditions; and several Materials Support Programs directed to advanced materials and refractory metals for all alkali metals, and Hg loop corrosion.

Knolls Atomic Power Lab., Schenectady, N. Y. Compatibility of Materials in Liquid Metal. Vail, D. B. August 18, 1951. Changed from Official Use Only June 26, 1956. 103p. Contract W-31-109-Eng-52.

A series of tests were initiated to determine the materials which are best suited for use as Na- or NaK-lubricated bearings under conditions of boundary lubrication. In order to evaluate the compatibility of materials for use in slider, hydraulic piston, or anti-friction bearings a compatibility tester was designed. The specimens constructed of similar or dissimilar materials are of two types. The sleeve specimen is rotated against a fixed specimen to which a known load is applied. A variety of materials have been evaluated under a limited set of conditions. Of the materials tested, exceedingly hard materials and Al alloys gave the best results.

NSA 11:2422

#### 4.400 SODIUM-POTASSIUM ALLOYS (NaK) LOOP DESIGN

##### 4.400 DUPLEX TUBE FOR SNAP-8 CORROSION LOOPS

B. E. Farwell

7 May 1962. AGN-EDS-159. Aerojet-General Nucleonics, San Ramon, Calif.

This engineering data sheet covers 9Cr-1Mo steel tubing clad with Type 316 stainless steel for use in the SNAP-8 corrosion loops.

##### 4.400 SNAP-8 MATERIALS TASK GROUP REPORT, AD-HOC COMMITTEE REPORT

L. Rosenblum, NASA (Chairman)

Pub. by Aerojet General Corporation, Azusa  
August 20, 1962

Review of critical problem areas relative to long life mercury and NaK systems. The neglected development of the NaK system and the poor corrosion resistance of the Haynes 25 alloy in mercury were discussed.

##### 4.400 LIQUID METAL CORROSION RESEARCH IN THE SNAP DEVELOPMENT PROGRAM

Perlow, M. A. and Page, J. P.

TID-7626 (Part 1), 1962

3rd Annual AEC-NASA Liquid Metals Corrosion Meeting

Corrosion studies of long life NaK loops using Type 316 stainless steel, Hastelloy N, Hastelloy C, and Haynes 25. Definite cases of intergranular attack were observed for Type 316 and Hastelloy N above 1200°F in NaK.

##### 4.400 NAA-SR-6439

##### SNAP 2 PRIMARY COOLANT DEVELOPMENT

Perlow, M. A.

(Atomics International. Div. of North American Aviation, Inc.  
Canoga Park, Calif)

July 15, 1961

Contract AT-11-1-GEN-8. 70 p.

The design, development, testing and selection of components integral to the primary coolant system for the SNAP 2 (Systems for Nuclear Auxiliary Power) reactor for space applications are described. Included are core hydraulic studies, heater (resistance element and transformer types) development, corrosion studies (NaK-78 is the primary coolant), NaK hydride precipitation studies, and lithium hydride (tentatively selected as the SNAP 2 radiation shielding medium) studies.

- 4.400 NaK Loop Equipment  
NAA-SR-5244 SNAP 2 Reactor Pump Development Program (Radial Gap Permanent-Magnet Pump), Sudar, S. (Sept. 1961).

A compact electromagnetic pump utilizing a rotating permanent magnet with radial gap was developed for possible application to the SNAP 2 Reactor coolant system. The pump was designed for circulation of NaK at 1000°K and 11.2 gpm with a developed pressure of 3 psi, operation at 40,000 RPM, minimum weight and size, and high reliability. The performance characteristics of four pump models were measured in a 1000°F NaK test loop and compared with design predictions. The capability of the pump design concept was demonstrated, though further development work is needed to meet the SNAP-2 pump requirements. A flow capacity of 6.8 gpm at 1000°F with head of 3 psi at 4000 RPM. Pump weight was 3 lbs.

4.400 LIQUID METAL HEAT EXCHANGERS

K. B. Schumacher

American Society of Naval Engineers, Inc., Journal, v. 72, Nov. 1960, p. 779-782.

Design and operation of a liquid metal heat exchanger. Corrosion of components by the NaK system. Prevention of tube leakage and failure by proper design and a manual relief valve system. 7 ref.

4.400 LIQUID METAL CORROSION RESEARCH IN SNAP (AI)

M. A. Perlow, J. R. Crosby, NASA TN-D-769, 1960.

Introduction to SNAP-2, SNAP-8, and SNAP-10 systems. NaK corrosion of containment materials is summarized.

NSA 15:13274

- 4.400 CNLM-2422, (Conf.), Pratt and Whitney Aircraft Division, United Aircraft Corporation. Connecticut Aircraft Nuclear Engine Laboratory, Middletown, Connecticut.  
Design of LNCSA-Type Corrosion Loop  
G. E. Coyle. March 22, 1960. 14 p.

... Li and NaK ...

ACR 18:1478

- 4.400 NUCLEAR ENGINEERING DEPARTMENT PROGRESS REPORT, MAY 1, AUGUST 31, 1960  
(Brookhaven National Lab., Upton, N. Y.) 66 p.

Includes: liquid metal heat transfer, steel thermal convection loops containing Hg and Na, Mercury Test Loop, and NaK Heat Transfer Loop. (J.T.J.)

NSA 15:20477

4.400

NP-8458

General Electric Co. Light Military Electronics Dept., Schenectady, N. Y.

Research on Liquid Metals as Power Transmission Fluids. Progress Report No. 4 (for) June 1, 1959 to February 1, 1960. R. C. Kumpitsch. Feb. 1960. 27p. Project No. 8-(1-7331). Contract AF33(616)-5917.

Continued effort was applied in establishing a 1 GPM 3000 psi, 1000°F, NaK-77 (liquid metal) flow test loop. This test loop, when completed, will be used in the research of determining the feasibility of using liquid metals as high temperature, hydraulic power transmission fluids. Progress is reported toward completion of the test equipment including completion of the low pressure portion (console) of the test loop, and installation of the high pressure NaK pump mounting and speed drive fixture in the inert atmosphere glove box. The high pressure NaK pump is currently 60 percent complete. Delivery of the unit is scheduled for April 15, 1960. Three components were added to the liquid metals test loop. These components consist of two over-pressure relief valves and a high temperature liquid metals servo. (For preceding period see NP-8457.) (auth)

NSA 14:11704

- 4.400 FWAC-593, (Secret) Pratt and Whitney Aircraft Division, United Aircraft Corporation, Middletown, Connecticut., Nuclear Propulsion Program Engineering Progress Report for July 1, 1959 - September 30, 1959. October, 1959. 127 p.

... NaK corrosion loops examined... ACR 16:215

- 4.400 NP-8457  
General Electric Co. Light Military Electronics Dept., Schenectady, N. Y.  
Research on Liquid Metals as Power Transmission Fluids. Progress Report No. 3 (for) March 1, 1959 to June 1, 1959. R. C. Kumpitsch. June 1959. 26p. Project No. 8-(1-7331). Contract AF33(616)-5917.

The research effort, during this report period, on liquid metals as power transmission fluids was concerned with establishing a 1-gpm, 3000-psi, 1000°F, NaK-77 test flow loop. The low-pressure portion (console) of the test loop has been completely assembled. A control panel for operation of the loop was fabricated. The "console" was installed in the liquid metals test area and completely instrumented, with exception to the loop's low-pressure sensing and recording equipment. The design of the high-pressure NaK pump mounting and speed drive fixture for the inert atmosphere "glove box" was completed. This mixture is currently being constructed. Continuing progress is being made on the manufacture of the high pressure-temperature NaK staged gear pump. No improvement in the delivery schedule for this pump has been obtained. Difficulty is being experienced in the procurement of correctly fabricated carbide material for this NaK pump. Negotiations are currently underway with both the pump and material vendors to resolve the problem. The revised liquid metals program schedule is included. (auth) NSA 14:11703

- 4.400 RESEARCH ON LIQUID METAL AS POWER TRANSMISSION FLUIDS  
Progress Report No. 1 For September 1, 1958 to December 15, 1958. (R58 APS 116) General Electric Co., Light Military Electronics Dept., Schenectady, N.Y.  
R. C. Kumpitsch. Dec. 1958, Project No. 8 - (1-7331). Contract AF33 (616)-5917.

Research concerned the construction, assembly, and operation of a complete 1 gpm, 3000 psi, 1000°F liquid metals test loop is reported. This loop will test the feasibility of using NaK-77 as a high temperature hydraulic fluid.

NSA 13:20182

- 4.400 THE USE OF SODIUM AND SODIUM-POTASSIUM ALLOY AS A HEAT TRANSFER MEDIUM  
Hall, W. B. and T. I. M. Crofts  
Proc. Inst. Mech. Engrs. 170, 321-39 (1956)

A number of Na and NaK circuits which have been built and operated over the past 3 years for heat-transfer experiments are described. The design and construction of liquid metal circuits and the components which are commonly used in them are discussed.

CA 51:7065

- 4.400 NP - 5714  
Liquid Metal Technology. Final Report. (A review of the work from May 1949 to May 1954 with abstracts of reports issued).  
R. C. Werner. Mar. 29, 1955. 77 p. Contract N9onr-85801.

A final summary is presented of the various activities which have been carried out on liquid Na and NaK plumbing systems. Results on heat transfer, flow properties, corrosion tests, accessibility, Na cleaning, and tests on valves, bellows, pumps, etc. are included. Approximately half the report consists of abstracts of the various technical reports and memos which have been issued under the contract. (For preceding progress report see NP-5601.)

REPORT NO. 1 ON 1000 KW SYSTEM

Tidball, R. A., F. L. Mangold and S. N. Tower  
 Mine Safety Appliances Company, Callery, Penna.  
 Memo Report No. 49, October 15, 1953. 14p.

The 1000-kw heat transfer system was designed to test pilot plant size liquid metal system components at temperatures to 1400°F. The test program was divided into phases: transferring heat to air and transferring heat to boiling water. Two liquid metal systems to prevent exposing the tubes of the liquid metal heater to full steam pressure in event of a failure of the steam generating equipment were used. The air cooled system is shown schematically. The NaK was circulated by a rotary magnet pump, through a flowmeter into the NaK heater. The discharge from the heater was piped to the tube side of the intermediate heat exchanger, and returned to the pump. Sodium was circulated by a DC conduction pump, through the flowmeter, the shell side of the intermediate heat exchanger, a swing check valve to the sodium cooler. Discharge of the sodium cooler passed through a stop valve, an a-c conduction pump to the suction of the d-c pump. The sodium was cooled by an air blast over finned tubes. Both NaK and sodium systems were fitted with diffusion type cold traps, expansion tanks, and emergency dump tanks. The sodium piping was fitted with tubular heaters (strapped to the outer surface) to preheat the piping before charging. Tests of the major components of this unit at various loads and temperatures are reported.

NP - 5872

REPORT NO. 1 on 1000 KW SYSTEM. Memorandum Report No. 49.

R. A. Tidball, F. L. Mangold, and S. N. Tower. Oct. 15, 1953.  
 14p.

The 1000-kw heat transfer system was designed to test pilot plant size liquid metal system components at temperatures to 1400°F. The test program was divided into phases: transferring heat to air and transferring heat to boiling water. Two liquid metal systems to prevent exposing the tubes of the liquid metal heater to full steam pressure in event of a failure of the steam generating equipment were used. The air cooled system is shown schematically. The NaK was circulated by a rotary magnet pump, through a flow meter into the NaK heater. The discharge from the heater was piped to the tube side of the intermediate heat exchanger, and returned to the pump. Sodium was circulated by a DC conduction pump, through the flow meter, the shell side of the intermediate heat exchanger, a swing check valve to the sodium cooler. Discharge of the sodium cooler passed through a stop valve, an a-c conduction pump to the suction of the d-c pump. The sodium was cooled by an air blast over finned tubes. Both NaK and sodium systems were fitted with diffusion type cold traps, expansion tanks, and emergency dump tanks. The sodium piping was fitted with tubular heaters (strapped to the outer surface) to preheat the piping before charging. Tests of the major components of this unit at various loads and temperatures are reported.

ANL - 4554

EXPERIMENTAL BREEDER REACTOR PROJECT. REPORT FOR THE PERIOD  
FEBRUARY 1, 1950, THROUGH MARCH 31, 1951.

R. A. Cameron,  
 B. C. Cerutti, L. J. Koch, H. V. Lichtenberger, D. F. McGinnis,  
 M. Novick, E. N. Pettitt, H. E. Stanton, E. F. Stone, G. K. Whitham.  
 April 1, 1951. Decl. Jan. 17, 1957. 60p.

The design of a pressure gauge system to show pressure changes in the fuel rods throughout the Experimental Breeder Reactor (CP-4) is described. Apparatus has been designed and built for filling the annulus in the lower section of the CP-4 fuel rod with NaK alloy. The procedure for adding NaK to fuel rods is described. The design of a totally enclosed liquid metal pump for the cooling circuit of the CP-4 is described in some detail. Results are given of a test of this pump in a NaK alloy coolant loop to determine its hydraulic characteristics. The design and operation of pressure transmitter unit for the reactor coolant system are described. Tests have been carried out to determine the heat transfer characteristics of a full size steam generator tube assembly under full power conditions. Design details and construction specifications of the tube are shown. Characteristics are shown of a gas circulating blower tested operating on air.

See Also: 2.340, 2.350, 5.240, and 6.500.



Report for the Period March 1, 1948 Thru November 30, 1948.  
 Reactor Engineering Division. W. H. Zinn, director. Feb. 3,  
 1949. Decl. Mar. 28, 1957. 67p.

Detailed design and operational data on a NaK circulation system is presented. Design information on electromagnetic pumps is included. 39 figures.

#### 4.410 CORROSION DEPENDENCE ON SYSTEMS CONFIGURATION

- 4.410 Metallographic Examination of High Velocity Heat Exchanger (SHE #1)  
 R. J. Gray, May 24, 1956. Decl. Out. 9, 1959. 14p. OTS  
 NSA 14:2537. CF-56-5-148 ORNL

The intergranular attack by NaK is examined. The acceleration of grain growth due to the strain anneal effect, and the effects of thermal expansion and differential across the tube wall were directly related to the operating temperature at the hot end. Mass transfer was present where the NaK entered the heat exchanger, but the deposition was influenced greatly by flow against the tube walls.

- 4.410 KAPL-M-WLF-5  
 Knolls Atomic Power Laboratory, Schenectady, N.Y.  
Examination of the Natural Circulation Steam Generator From the  
Liquid Metal Heat Transfer Test Facility at Alplaus, New York.  
 Report No. 2  
 Callahan, E. J. and W. L. Fleischmann  
 September 12, 1953. Changed from Official Use Only Oct. 8, 1956. 35p.  
 Problem No. 70: Investigation of the Causes of Cracking in the  
 Natural Circulation. Contract W-31-109-Eng-52

The first structural failure of a heat exchanger used in the Alplaus liquid metal system is discussed. The metallurgical examination revealed failure of two Type 347 stainless steel tubes (NaK outside, mercury inside) and two tube sheets. The location of the failure was confined to the hot end and the area around these two hottest tubes. Judging by the fracture appearance, the majority of the cracks were caused by thermal cycling. Further studies are under way to establish more definitely the cause of the failure.

NSA 11:3791

- 4.411 Solubility of Sodium Monoxide in NaK  
 Rodgers, S. J. and J. W. Mausteller  
 Mine Safety Appliances Company, Callery, Penna. Technical Report  
 No. 47 Contract NObs-65426. March 15, 1956. 9p.

The concentration of oxygen (added as Na<sub>2</sub>O) in NaK-24 (24 wt.% potassium) and NaK-44 was studied as a function of temperature. Oxygen concentrations are higher for higher temperatures. Curves are presented for oxygen concentration versus temperature and potassium content for NaK-24, NaK-44 and NaK-78. Up to 550°F the oxygen concentrations are independent of potassium content of the sodium, but above 550°F the curves diverge to reach oxygen saturations at 1000°F of 0.20, 0.15, 0.085 and 0.050 wt. % O<sub>2</sub>, respectively, for sodium, NaK-24, NaK-44 and NaK-78. These data can be applied to the problem of oxide precipitation by a leak from a third-fluid NaK system to a sodium system high in oxygen content. Below 0.010 wt. % O<sub>2</sub> in the sodium there would be no problem. Above this value precipitation would depend on the potassium content, temperature, and oxygen content, but the effect would be of little consequence in a well-designed sodium system.

- 4.412 To be expanded in the supplement.

- 4.413 To be expanded in the supplement.

- 4.414 SELECTION OF LIQUID-METAL PUMPS BY HAMMITT  
F. G. (Univ. of Michigan, Ann Arbor) Chem. Eng. Progr. 53,

The design and development of large-scale, liquid-metal circulating pumps such as would be suited to application in nuclear power plants have been investigated. Fluid dynamic problems-cavitation and erosion damage to the structural components at the high relative velocities obtained in the pump impeller - were the particular concern.  
CA 51:10139

- 4.414 LIQUID METAL CAVITATION PROBLEMS AND DESIRED RESEARCH  
Hammit, Frederick G., American Society of Mechanical Engineers,  
Paper No. 60-HYD-13, 1960, 7 p.  
Rev. of Met. Lit. 17:5

Cavitation of liquid Na, K, Rb, Na-K alloys, Hg, Bi and Pb-Bi alloys as heat-engine fluids versus H<sub>2</sub>O. Temperature, density of liquid, density of vapor, viscosity, surface tension, heat capacity latent heat, thermal conductivity, vapor pressure and bulk modulus. (R2m, 14-60, Hg, Na, Na-b, Bi, Pb-b).

- 4.414 Cavitation in a Venturi Tube Passing NaK. (78%K.) Alloy at 200-300 C  
Crofts, T.I.M.  
Great Brit. Windscale Works, Sellafield Cumb., England  
RDB(W)/TN-160 Aug. 1954. 18p. (FRDC/P-72)

Tests with NaK (78% K) eutectic alloy at 200 to 300 C in a venturi tube show that cavitation takes place at pressures approaching absolute zero. The effects of gas entrainment and also of a magnetic field were studied.  
NSA 13:10377

- 4.414 CF-54-8-225  
Oak Ridge National Lab., Tenn.  
Some Observations Made on Cavitating Sodium Flow in a Venturi by J. M. Trummel. Aug. 31, 1954. 10p Contract W-7405-eng-26.

Cavitating sodium flow was obtained in the venturi of an isothermal loop at temperatures from 1215 to 1475° F. Cavitation was detected in three ways: by observing the minimum venturi throat pressure, by observing the loop pressure drop, and by listening to the flow noise. Cavitation occurred promptly when venturi throat pressure was reduced to within about 1.5 psia of vapor pressure. Venturi wall damage due to cavitation has not been determined.

NSA 11:13710

#### 4.420 WELD STRUCTURE, BRAZEMENTS, AND CONNECTIONS

To be expanded in the supplement.

#### 4.430 FATIGUE OF EXPANSION/CONTRACTION OF COMPONENTS

See: 4.330

#### 4.440 BEARINGS AND BEARING SURFACES

- 4.440 KAPL-589  
Knolls Atomic Power Lab., Schenectady, N. Y. Compatibility of Materials in Liquid Metal. Vail, D. B. August 18, 1951.  
Changed from Official Use Only June 26, 1956. 103p.  
Contract W-31-109-Eng-52.

A series of tests were initiated to determine the materials which are best suited for use as Na- or NaK-lubricated bearings under conditions of boundary lubrication. In order to evaluate the compatibility of materials for use in slider, hydraulic piston, or anti-friction bearings a compatibility tester was designed. The specimens constructed of similar or dissimilar materials are of two types. The sleeve specimen is rotated against a fixed specimen to which a known load is applied. A variety of materials have been evaluated under a limited set of conditions. Of the materials tested, exceedingly hard materials and Al alloys gave the best results.  
NSA 11:2422

4.440

KAPL-877  
Summary of Journal Bearing Tests With Copper Bearing and Tungsten Carbide Journals Operating In Sodium-Potassium Alloy. Vail, D. B. Feb. 3, 1953. Decl. Jan. 10, 1956. 27p. Contract W-31-109-Eng. 52.

Tests were performed on two 2 3/8 inch diameter hydrodynamic journal bearings with sodium-potassium alloy as a lubricant. The first test was made with an electrolytically copper-plated bearing and 18-4-1 high speed, tool-steel guide bearings operated against a tungsten carbide journal. The second test was run with an electrolytically copper-plated bearing and tough pitch copper guide bearings operated against a tungsten carbide journal. Tests were run with speeds of 1200 and 1700 rpm and with liquid metal temperatures from 100 to 500°F. The duration of the respective tests was 376 hours and 1483 hours. Data are tabulated.

NSA 10:10821

4.440

KAPL-M-EGB-16  
 Knolls Atomic Power Lab., Schenectady, N. Y.  
Aluminum Bearing Alloys in Sodium. Report No. 2 on Evaluation of the Behavior of Aluminum in Sodium. Problem No. 28. Brush, E. G., April 6, 1954. 15p. Contract W-31-109-Eng-52.

Simulated bearing tests have shown that certain Al base alloys have attractive bearing properties for service in Na and NaK. Previous corrosion tests have shown that the behaviour of Al in Na is greatly influenced by the presence of stainless steel. To study this influence under simulated bearing conditions, non-rotating sleeve and journal tests were run in Na at 300, 400 and 500°C. Additional tests were made to determine the solubility of Al in Na as a function of temperature. The tests reaffirm previous findings that at temperatures above 400°C, the high corrosion rate of Al base alloys prohibits their use in Na-stainless steel systems.

4.440

AERE-R/R-1891  
 Gt. Brit. Atomic Energy Research Establishment, Harwell, Berks, England. Some Preliminary Tests on Bearing Materials to Operate Under Liquid Sodium-Revised Interim Report. June 1954; D. F. Elliott et al. April 23, 1956; Decl. September 17, 1957; 37 pages.

The object of these tests is to determine the most suitable materials to be used in the construction of bearings for a 50 H.P. Sodium Pump. The most critical period of operation for these bearings is during start up, when a condition of 'boundary lubrication' will exist, and metal-to-metal contact will occur between the rotating shaft and the bearing until the speed of the pump shaft is sufficient to give true 'hydrodynamic lubrication' by creating a continuous film of sodium within the bearing. The characteristics required for a suitable pair of bearing materials are given. The results of these tests may also be useful in the selection of materials for use as rubbing surfaces in reactor mechanisms which are required to operate submerged in liquid Na or Na-K alloy.

NSA 12:3639

4.440

KAPL-1079  
The Performance of Tungsten Carbide Journal Bearings Operating In Liquid Metals. Vail, D. B. Jan. 25, 1954. Changed from Official Use Only June 26, 1956. 49p. Contract W-31-109-Eng-52.

The results of a series of tests indicated that liquid-metal-lubricated journal bearing performance may be predicted adequately by existing theoretical and empirical concepts. Test performance of the journal bearings was closely correlated with the theoretical performance postulated by Cameron and Wood for a full journal bearing. The calculated minimum film thicknesses were also shown to be as empirically postulated by Cameron. In the range of boundary lubrication it was observed that tungsten carbide ceramal bearings resisted the immediate seizure characteristics shown by other alloys, but that some roughening of the bearing surfaces occurred for the particular ceramals used in this series of tests.

NSA 11:2448

Basic Information on the Bearing Properties of Various Materials in Liquid Metals. Greenert, W. J. and Gross, M. R.  
NEES, Annapolis. EES-090014A 19 Feb. 1954, 28p. AD-146169

Evaluation of materials for use in antifriction bearings exposed to liquid sodium-potassium alloy is presented. In order to establish certain basic information, however, many of the tests described were performed in lubricating oil. Data represented on the load carrying capacity of SAE 521000 and 18-4-1 high speed tool steel in oil at 400 F. Superiority for the high speed tool steel was found. Also, the plastic behavior of rollers subjected to high stresses is discussed, and dispersion in the results of the contact roller test is statistically analyzed. The effect of liquid metal on laminated phenolic and glass laminated melamine plastics is presented. It is concluded that the maximum operating temperatures for these materials is 275 F. Results are also presented on the effect of liquid metal on the fatigue strength of SAE 521000 steel. The conclusion is that liquid sodium-potassium is not detrimental to the fatigue properties of this steel.

NSA 13:14508

The Use of Rolling Contact Bearings in Molten Alkali Metals.  
W. Markert, Jr. and K. Mildred Ferguson. July 24, 1952.  
Decl. Nov. 30, 1956. 124p. (NP-4130; ES-401-22; Project  
"Baby" Report No. 5061)

A series of tests have been conducted on full size rolling-contact bearings for use as rotor bearings in a large liquid metal pump. These bearings were required to operate submerged in and lubricated by liquid Na or NaK of low viscosity at a temperature of approximately 250°F and speeds of 850 and 1800 rpm. It was found that rolling-contact bearings had a considerable capacity under these conditions, although it was considerably less than their capacity with normal lubrication. It was also found that failures did not have normal fatigue characteristics and that the primary cause of failure could be attributed to the retainer. Various retainer designs and materials were investigated. Very little difference in life was obtained when bearings with different capacities under normal lubrication were tested under these conditions. Many types of rolling-contact bearings were investigated. These included ball bearings, straight roller bearings, tapered roller bearings, ball thrust bearings, and retainerless bearings. Tests were conducted through a range of thrust loads from 300 to 4000 pounds. Several tests were also conducted under conditions of pure radial load ranging from 600 to 1200 pounds.

Failure of Liquid Metal Pump and Resulting Damage to Pump And Test Facility. James J. Owens. Jan. 5, 1951. 59p.  
(NP-3380)

The large (2900 gpm) Byron Jackson liquid metal pump, which was under test, failed and the resulting leakage of NaK alloy to the atmosphere caused a fire. This failure was caused primarily by one of the ball bearings which broke and pierced the stainless steel liner. An account of events leading up to the fire, a description and analysis of the pump and bearing failure, an account of the pump damage, and an estimate of the cost of repair are included in the report. Also included are descriptions of the cleaning of the pump and circuit, the disassembly of the pump, and a number of recommendations.

Investigation of Liquid Metal Lubricated Bearings.  
Apkarian, Harry. GE, GE&CL, Schenectady, N. Y. Nov. 27,  
1950. Decl. Mar. 19, 1957 10p. R-50GL231.

The liquid metal lubricated bearing program was an investigation to determine (1) the feasibility of using liquid metals as bearing lubricants, (2) characteristics and behavior of bearings with liquid metal lubricants, and (3) design criteria for liquid metal lubricated bearings. The liquid metal lubricant used was a mixture of 50% Na and 50% K by weight. It was determined that liquid metals, such as NaK, when used as lubricants behave in accordance with established hydrodynamic principles in much the same manner as any conventional lubricant. Properly designed bearings lubricated by liquid metal will support practical loads through a wide range of temperature and speed.

NSA 12:1926



5.000

EFFECT OF LOOP OPERATION  
ON PERFORMANCE



5.100 SURFACE PREPARATION OF CONTAINMENT MATERIAL

5.100 STEAM CLEANING FACILITY FOR LIQUID METAL COOLED FUEL ELEMENTS

Brinkman, H. L., and Wilson, W. (AMF Atomics, Greenwich, Conn.).  
Trans. Am. Nuclear Soc., 4: No. 2,235-6(Nov. 1961)

NSA 16: 675

5.100 NUCLEAR REACTOR HEAT TRANSFER TECHNOLOGY

M. E. Lapidès, General Electric Company, Pa. "Progress in Nuclear  
Energy," Ser. IV 4:29-50 (1961)

Contains analytical and experimental data on heat transfer  
for liquid metals. Effects considered include, among other things, surface  
roughness.

NSA 16:12831

5.100 SPECIFICATION FOR CLEANING METAL COMPONENTS AND SYSTEMS FOR LIQUID-  
METAL COOLED POWER REACTORS

Kovac, L. R.  
(Atomic Power Dev. Ass. Inc., Detroit, Mich.) AECU-3747, 10 p.  
(Jan 13, 1958)

The degree of cleanliness is defined, and the methods and materials  
to be used are outlined for carbon and low alloy steels, 300 and 400 series  
ferritic and austenitic stainless steels, special Ni-Cr base heat-resistant  
hard-facing and high-temperature brazing alloys, and some non-ferrous  
materials.

AD 256 511

5.100 Attack of Unstressed Metals by Liquid Mercury

J. F. Strachan and N. L. Harris. J. Inst. Metals 85, 17-24 (1956)  
(Paper No. 1715)

The solubilities and wt. losses in the absence of air at room temper-  
ature of most of the metallic elements in static liquid Hg were detd., usually  
to 0.001%, by chem. analysis of the solns. and by weighing the specimens.  
The solubilities show a periodic relationship with the at. no., and there  
are indications that this can be related to the inner electronic shell struc-  
ture. In general, the solubilities of the B sub-group elements exceed those  
of the true metals, while of this latter group the transition metals show the  
lowest values. When attack occurs, it involves wetting, surface amalgamation,  
soln, and occasionally combination and intergranular penetration. Oxidation  
brought some metals out of soln. in Hg and led to ambiguities.  
Exposure to air can result in a form of mass transfer. No significant changes  
occurred in the mechanical properties of Fe, Mo, some steels, and Ni alloys  
after 2000 hrs. in Hg at 500°. Ni suffered a decrease in maximum stress, yield  
stress, and elongation of about 50%. Severe cavitation erosion of metals and  
alloys, normally resistant to Hg, occurred at room temperature on the applica-  
tion of 30 kc./sec. ultrasonic vibrations.

CA 51-981h

5.100 See Also: 1.400, 1.410, 1.610, and 3.400.



5.110 CLEAN-UP AND PREPARATION REQUIREMENTS FOR MERCURY SYSTEMS

5.110 See: 1.410, 1.520, 3.410.

5.120 CLEAN-UP AND PREPARATION REQUIREMENTS FOR POTASSIUM,  
SODIUM AND NaK SYSTEMS

5.120 NAA SR Memo 6408 Snap-2 Primary System  
Test - Objectives, System Description and Procedures, G. M. Kiken,  
June 21, 1961

Among other things, this report describes a mobile loading system  
for NaK capable of cleaning NaK prior to final loop sealing.

NSA 16:5084

5.120 TID-7568 (Part 2)  
OPERATING EXPERIENCES WITH OXIDE MONITORS FOR SODIUM SYSTEMS.  
E. F. Batutis. P.24-32 of ANALYTICAL CHEMISTRY IN NUCLEAR REACTOR  
TECHNOLOGY. PART 2. INSTRUMENTATION, REMOTE CONTROL TECHNIQUES,  
AND NUCLEONICS SECOND CONFERENCE, GATLINBURG, TENNESSEE,  
September 29-October 1, 1958 9p. \$2.50(OTS).

TID 3544  
NSA 13:14247

5.120 CF-55-7-16  
Oak Ridge National Lab., Tennessee  
Effect of Pre-Cleaning of Glass Samples on the Oxygen Content of  
Sodium, White, J. C., July 5, 1955, Decl. April 4, 1956. 3p.

Molten Na flushing exerts a cleansing action on glass Na sampling  
tubes. The O<sub>2</sub> content of the Na used in this study was so high that the  
results are not conclusive for the chromic acid cleansing. NSA 10:10708

5.120 KAPL-P-1511  
Knolls Atomic Power Lab., Schenectady, N. Y.  
RECLEANING SODIUM HEAT TRANSFER SYSTEMS.  
W. H. Bruggeman, H. F. Karnes, and F. C. Hanny. (1956). 31p.  
Contract (W-31-109-Eng-52). \$6.30 (ph OTS); \$3.00 (mf OTS).

Both steam and alcohol are useful techniques for the removal of  
sodium residues from piping systems and components. The principal disadvantage  
of steam recleaning is the possibility of high temperature excursions due to  
the low heat capacity of the steam. Tests have been conducted in which these  
temperature rises are minimized by dilution of the steam with an inert gas.  
This humid gas technique is recommended for recleaning operations where the  
use of steam would be preferable to alcohol and where local over-temperature  
could result in system equipment damage. (auth)

NSA-10-7622

- 5.120 KAPL-M-SCT-8  
Knolls Atomic Power Lab., Schenectady, N. Y.  
Mark B Pump Cleaning Report. Demers, R., Oct. 7, 1955. 12p.  
Contract W-31-109-Eng-52.

Sodium cleaning of the Mark B Pumps was successfully completed without incident. However, an additional step, (a tri- $\text{NaHPO}_4$  flush) had to be incorporated into the cleaning procedure to remove an oily-type film which was deposited after Na cleaning. This T.S.P. did not remove all of the residue and localized swabbing with acetone on all accessible parts of the pump interior was necessary. Analysis of the residue indicated that the oily film could have been deposited by the methyl isobutyl ketone, one of the cleaning agent's constituents. The ketone apparently undergoes a condensation reaction to form a water insoluble soap-like compound. In view of the above, SIR systems development has suggested that an alcohol which does not contain this constituent be employed in future pump cleaning operations. If the oil film deposit is still evident after the use of absolute alcohol, it is suggested that the final water rinse be followed by a cold acetone flush in place of the T.S.P. solution. This would ensure maximum cleanliness of the inaccessible expansion joint. Residual acetone could be readily removed by hot gas purging.

NSA 10:9776

- 5.120 NP-5811  
WETTING WITH SODIUM. Technical Report No. 43. M. H. Wahl.  
Nov. 8, 1955, 13p. Contract NObs-65426.

Certain pretreatments (aqua regia, NaOH, electropolish, and  $\text{Na}_3\text{PO}_4$ ) have been shown to enhance wetting of stainless steel by molten Na at low temperatures. Wetting was neither speeded nor retarded by contact with cover gas (98% $\text{N}_2$ -2% $\text{O}_2$ ).

- 5.120 KAPL-M-EDL-100  
Knolls Atomic Power Laboratory, Schenectady, N. Y.  
NaK Flushing of Sodium-Contaminated Test Equipment by Bissonnette,  
P. E., July 1, 1955. 15 p. Contract W-31-109-Eng-52.

Sodium-potassium flushing was tested in order to determine its efficiency in removing Na from a test fixture after testing. It was determined that the use of this method facilitates disassembly of the test fixture.

NSA 11:11569

- 5.120 Removing the Sodium Residue from the Alphas Main Heat Transfer System with Ethylene Glycol, W. W. Kendall and M. Nazar. Aug. 5, 1954. 21 p. (KAPL-M-WWK-5)

The Na residues were cleaned from the Main Alphas Heat Transfer System to remove all Na from the system for base shutdown and to demonstrate the use of ethylene glycol in cleaning a large scale system. The latter objective is in support of the program for developing a non-Na flushing agent for use in the Mark B Coolant System. All residual Na was cleaned from the system. Slight traces of C was found on the inside of the pipe by wiping with a white cloth. The decomposition of the glycol caused operational difficulties such that ethylene glycol cannot be recommended as the non-Na flush for Mark B.

- 5.120 KAPL-M-GJB-2  
Knolls Atomic Power Laboratory, Schenectady, N. Y.  
Sodium Flush Program by Barenborg, G. J. dated Nov. 12, 1954. 10p.  
Contract W-31-109-Eng-52.

A research program for development of a sodium flush procedure for the SIR is described. The purpose of the procedure would be to allow early access to the lower reactor compartment following operation.

NSA 11:13156

- 5.120 See Also: 1.400, 1.410, 1.420, 3.430, and 4.411.

## 5.200 PURIFICATION, GETTERING, AND FILTERING OF LIQUID METALS

### 5.200 PROCESS OF RECOVERING ALKALI METALS

Jasper Wolkoff (to USAEC) U. S. Patent 2,996,375.  
Aug. 15, 1961

A process is described of recovering alkali metal vapor by sorption on activated alumina, activated carbon, dehydrated zeolite, activated magnesia, or Fuller's earth preheated above the vaporization temperature of the alkali metal and subsequent desorption by heating the solvent under vacuum (AEC).

NSA 15:24801

### 5.200 LIQUID METAL PURIFIER

(To Babcock & Wilcox Co.) British Patent 809,584  
Feb 25, 1959.

A cold trap device for removing oxides from liquid-metal systems is described.

NSA 13:12725

### 5.200 NF - tr - 642

Liquid-Metal Coolants in Nuclear Reactors, Andrew, P.A.  
Kanev, A. A., Fedorovich, E. D., translated from  
a Russian publication, Leningrad 1958, 463 pp.

Information on the properties of liquid metals used as coolants in nuclear reactors is presented. Topics discussed include heat transfer in the liquid phase or during boiling and condensation, the interaction of liquid metals with structural materials, methods for removing impurities from liquid metals, and the peculiarities of design and operation of systems with liquid metals as coolants. The requirements to be met by heat transfer media used in nuclear reactors and ways to raise the efficiency of atomic power plants employing liquid metal coolants are outlined.

NSA 15:24538

### 5.200 CONTROL OF OXYGEN IN SODIUM HEAT-TRANSFER SYSTEMS by Gray, I. L. et al. (General Electric Company, San Jose, Calif.) Chem. Eng. Progr. Symposium Ser. 53, No. 20, 11-18 (1957). CA 51:16010

### 5.200 Geller, W., "On the Theory of De-Gassing of Liquid Metal by Scavenging Gas.", 1943. 18 p.

A general theoretical treatment of the removal of dissolved gases from liquid metals by a scavenging gas is given. It is assumed that the gas phase and metal phase are in equilibrium so that the limits which can be attained in practice are established. The laws are derived for gas removal by scavenging with bubbles of finite size, for diffusion in one gaseous volume only, and for scavenging with infinitely small bubbles. Application of the theory to removal of CO<sub>2</sub> from H<sub>2</sub>O by air and removal of N<sub>2</sub> from steel by CO is described.

NSA 12:13149

5.200 See Also: 1.620, 2.300, 3.200, 3.400, and 6.500.

5.210 MERCURY (Hg)

5.210 PURIFICATION OF MERCURY METAL

K. Koyama. Nov. 20, 1955 4p. (HW-40123)(G.E.)

A purification method for Hg which employs a rotary scrubber and wash solutions of acid, water, and methyl-alcohol is described. The Hg is subsequently filtered on gold-adhesion filter. Various methods to determine purity is discussed.

NSA 14:12527

5.210 See Also: 1.620, 2.310, 3.212, 3.410, and 6.500.

---

5.220 POTASSIUM (K)

5.220 OXYGEN PARTITIONING IN POTASSIUM-OXYGEN REFRACTORY METAL SYSTEMS

A. P. Litman and J. R. DiStefano, Oak Ridge National Laboratory, 12th Annual AEC Corrosion Symposium, May 20-22, 1963, Castlewood, Pleasanton, California.

Impurities such as oxygen, nitrogen, and carbon in either a refractory metal or an alkali metal can have a significant effect on compatibility of the system. In some cases the impurity concentrations sufficient to cause deleterious effects are only several hundred parts per million - levels which might be present in "high-purity" metals.

For the case of oxygen in refractory metal-alkali metal systems, this problem is especially important for two reasons: (1) low oxygen concentrations are difficult to obtain and maintain in these metals and (2) at the temperatures required for many applications, oxygen diffusion rates are high. In some systems a deleterious effect of oxygen partitioning is unfavorable modification of the mechanical properties of the refractory metal. Another possible result is the plugging of cooler regions of flowing systems by precipitated alkali metal oxides if sufficient quantities of oxygen have been leached from the refractory metal.

A method to predict the equilibrium distribution of oxygen in refractory metal-alkali metal systems from available thermodynamic and solubility data is presented. Results are compared with experimental data for the niobium-oxygen-potassium and zirconium-oxygen-potassium systems at 815°C.

5.220 NUCLEAR FUELS AND MATERIALS DEVELOPMENT (SUPPLEMENT)

(TID-11295 Suppl.)

(Division of Reactor Development, AEC) Feb. 1961. 52p.

Liquid-metal compatibility studies are reported. Batches of K were purified by hot gettering and subsequent cold trapping to produce a relatively pure material for use in compatibility and heat transfer experiments. Nine refluxing K compatibility tests were conducted to provide screening information regarding the comparative corrosion resistance of Fe, Ni, Co, and Nb alloys. Results of boiling K loops are discussed.

NSA 15:14646

5.220 See Also: 1.620, 2.320, 3.222, 3.420, and 6.500.

---

5.230 SODIUM (Na)

5.230 NAA - SR - Memo 2830

Sintered Metal Filters for Sodium Coolant Systems

McDonald, J. S.

Atomic International, Div. of North American  
Aviation, Canoga Park, California, June 27, 1958, 10 p.

Equations which express the relations between the pressure drop, pore size, flow rate, and filter thickness for sodium flowing through sintered metal filters were derived.

NSA 14:19055

5.230 Material Transport in Sodium Systems by Haag, F. G. (General Electric Co., Schenectady, N. Y.)  
Chem. Eng. Progr. Symposium Ser. 53, No. 20, 43-50 (1957).

Data on the cause and magnitude of atom redistribution in flowing Na systems are summarized. System parameters are discussed, and O<sub>2</sub> concentration and temperature are shown to be the significant variables. The radioactivity from the growth of radioactive structural isotopes in typical Na-cooled reactor systems is small.

CA 51:16011

5.230 KAPL-M-NGM-2

Knolls Atomic Power Lab., Schenectady, N. Y.

Distribution of Uranium and Uranium Oxide in Liquid Metal Thermal Convection Loops by Mills, N. G. and R. F. Loenig. Jan. 23, 1951. Decl. March 9, 1957. 12p. Contract W-31-109-Eng-52.

Two tests were performed in Na thermal convection loops to obtain on indication of (1) where U or UO<sub>2</sub> would deposit in the SIR system in the event of a fuel pin failure and (2) how the dispersed fuel could be removed. It was also hoped that the results might apply as well to fission products since they appeared to accompany U in the experiment.

NSA 11:12564

5.230 COMPONENTS - HIGH PURITY SODIUM SYSTEMS

J. E. Kemme (LASL) p. 229-33 of Proceedings of the 1957 Fast Reactor Information Meeting held at Chicago, Ill., Nov. 20-21, 1957

A series of small, pumped, sodium loops was used to study the problems peculiar to a LAMPRE-type reactor. The ultimate purpose of these experiments is to discover a means of purifying sodium. A description and results of the tests are given.

NSA 13:16600

5.230 BMI-1213

PROGRESS RELATING TO CIVILIAN APPLICATION DURING JULY 1957

R. W. Dayton and C. R. Tipton, Jr., Aug 1, 1957, Decl. March 30, 1960. 56 p. Contract W-7405-eng-92. OTS.

Includes determination of oxygen in liquid Na by gettering.

NSA 14:21882

5.230 PURITY CONTROL IN SODIUM-COOLED REACTOR SYSTEMS.

Warren H. Bruggeman (Knolls Atomic Power Lab., Schenectady, N.Y.). A.I.Ch.E. Journal 2, 153-6 (1956) June.

Recent advances in purity control in sodium systems are covered. Emphasis is placed on results from the prototype SIR system as well as other unpublished data. Included are chemical and nuclear activation analyses of sodium, filtration data, and details and operation of cold traps and plugging indicators. (auth)

NSA 10:6631

- 5.230 KAPL-M-HFK-3  
HYDROGENOUS LOOP: WATER INJECTION TEST SDT-3 (on) RUN NO. W.1.-1  
H. F. Karnes. Sept. 12, 1955. 15p

Six grams of H<sub>2</sub>O were injected into the 1-inch hydrogenous loop at a temperature of 500°F. The pressure rise within the loop was more than 17 psi for at least 3/4 second and then decreased to 7.5 psi. Approximately 10% of the injected hydrogen was collected as gas in the surge tank. The balance is assumed to be in the form of NaOH and NaH. The plugging temperature of the Na increased from less than 300°F to 630°F after injection. Although the loop temperature was approximately 500°F, no flow restrictions were noted in the circulating system until flow was diverted to the plugging section. Cold trapping was successful in reducing the saturation temperature to 310°F. Hydrogen analysis of the Na confirmed the relative changes in plugging temperatures.

- 5.230 See Also: 1.620, 2.330, 3.232, 3.430, and 6.500.
- 

5.240 SODIUM-POTASSIUM ALLOYS (NaK)

- 5.240 A Skimming Process For Removal of Oxide From Surface of NaK Alloy. E. F. Inall, (Aust Mat'l U, Canberra) Brit. Chem. Eng. 6, 38607 (1961)

A method of skimming the film of oxide of NaK alloy from the surface of the liquid metal in a homopolar generator consists of pumping in from below the surface a cover gas, which rises in large bubbles to break the surface skin and causes waves which force the skin towards the skimming outlet. It then passes through a downward sloping pipe to a separating drum and through a steel-wool filter with 0.003" aperture.

CA 55:18519

- 5.240 A SKIMMING PROCESS FOR THE REMOVAL OF OXIDE FROM THE SURFACE OF SODIUM-POTASSIUM ALLOY  
E. K. Inall (Australian National Univ. Canberra)  
Brit.Chem. Eng., 6: 386-7 (June 1961)

Most of the oxides of NaK float on the surface at room temperature, therefore, it is difficult to entrain the oxides in a flow to a filter. A method used to skim the oxide from the main storage tank of a system handling 1000 gal of NaK is described that avoids any moving parts within the NaK system. A filter which is very suitable for holding a large load of filter cake from the NaK without blocking is also described.

NSA 15:21078

- 5.240 NYO-4811  
FIBROUS FILTERS FOR NaK FUME REMOVAL  
R. Dennis, et. al, Harvard Univ., Boston, Air Cleaning Lab  
May 1, 1960 40 p. Contract AT(30-1)-841. OTS.

...for Na and NaK coolant systems.

NSA 14:14960

- 5.240 TID-3544  
THE UTILIZATION OF A COLD TRAP TO STABILIZE SUSPENSIONS OF UO<sub>2</sub> IN NaK. P. R. Huebotter and W. R. Seitz. Nuclear Sci. and Eng. 5, 11-14(1959)Jan. NSA 13:5308

- 5.240 See Also: 1.620, 2.340, 3.242, 3.440, and 6.500.
-

### 5.300 REACTION OF CONTAMINANTS IN LIQUID METAL

- 5.300                    "Contact Thermal Resist in Heat Trans. to Liq. Metal,"  
O. P. Astakhov, V. I. Petrov and O. S. Fedynskii. At Energy (USSR)  
11 255-7 (1961)

The disagreement with the Martinelli-Lyon theory of published exptl. data on heat transfer to liq metals is attributed to the presence of an addnl. thermal resistance at the heat exchanger material - liq. met. boundary prob caused by impurities. Data on heat trans should be presented not in rate coordinates but in resist. coordinates. In the case of Na(l) flowing in Cu tubes (8.6 mm dia) at an ave. no temp of 240°C, the thermal contact resist varies between  $0.48 \times 10^{-5}$  and  $0.28 \times 10^{-5}$  met<sup>2</sup>-hr °C/kcal. When vel. of Na inside tubes is 1.58 - 11 met/sec. CA 56:1310h

- 5.300            NAA-SR-6386  
REMOVAL OF CARBON FROM LIQUID SODIUM SYSTEMS  
Anderson, W. J. (AI. Div. of N. Amer. Aviation, Inc., Canoga Park, Calif.) Dec. 1, 1961. Contract AT(11-1)-Gen-8. 25p.

Carburization of austenitic stainless steels has been observed to occur readily in carbon-bearing liquid sodium at 1000°F or higher. The high surface carbon content, 2 to 3%, caused by carburization in carbon-saturated sodium above 1000°F can produce a brittle case on the material. The carbon content of the carburized austenitic stainless steel depends on the degree of saturation of sodium with carbon. The effects produced by carburization revealed a need for control of carbon contamination in sodium systems. It was found that carbon could be removed effectively, either by calcium addition to sodium or by "gettering" through carburization of steel sheet in a carbon trap. The calcium addition was not considered to be immediately practical, because possible additional effects of the calcium in the system are unknown. The gettering method now is considered.

NSA 16: 4451

- 5.300            IMPURITIES IN A LIQUID METAL COOLANT AND THEIR EFFECT ON THE FUEL  
ELEMENT CANNING MATERIALS NIOBIUM AND VANADIUM  
Sinclair, V. M., Pool, R. A. H. and Ross, A. E.  
Nuclear Reactor Chemistry (Second Conference, Gatlinburg, Tenn.  
Oct. 10-12, 1961. No. TID-7622, July 1962. pp 35-56

Review of the properties of H<sub>2</sub>, N<sub>2</sub>, O<sub>2</sub>, and C in the primary coolant (70% Na-30% K) and effects of these nonmetallic impurities on the Cb and V fuel cans from 200°C to 800°C. 16 refs.

NSA 16:26475

- 5.300            CA55-19543g  
USP 2943034 June 28, 1960 to MSA, J. W. Mausteller.

The inhibitors decrease or prevent the mass transfer of radioactive constituents having a half life longer than Na<sup>24</sup>. Metals such as Ba, Sr, Ca, Ti, Sb, and Mg when used in amounts of approximately 1% by wt in a liquid Na heat transfer system using st steel or other alloy piping inhibit the mass transfer of the radioactive structural materials. Experiments are described showing that the order of effectiveness was the same as the order of listing above.

5.300 ZIRCONIUM AND TITANIUM INHIBIT CORROSION AND MASS TRANSFER OF STEELS BY LIQUID HEAVY METALS

O. F. Kammerer, J. R. Weeks, J. Sodofsky, W. E. Miller, and D. H. Gurinsky (Brookhaven Natl. Lab., Upton, N. Y.).  
Trans. Met. Soc. AIME 212, No. 1, 20-5(1958).

Zr and Ti inhibit soln. mass transfer of steels by liquid Bi, Hg, and Pb. It is shown that in Bi and Hg, these adsorb on the surface of the steels and subsequently react with N and possibly C from the steels to form inert, adherent surface layers of ZrN, TiN, or TiN + TiC. Data are presented which describe the condition under which these deposits form. These inhibitors decrease the soln. rate of Fe into Bi, and require a higher supersatn. for pptn. of Fe from Bi.

C. L. Mantell  
CA52-7091e

5.300 AERE-R/R-2190

Firman, E. C. et al. (United Kingdom Atomic Energy Authority, Research Group. Atomic Energy Research Establishment, Harwell, Berks, England) Experience Obtained on a Liquid Sodium Heat Transfer Rig 1954/1956. August 1957. 31 pages

Heat transfer data for Na flowing at moderately low Reynolds number in a double annulus heat exchanger are reported. The results qualitatively confirm the findings of coefficients well below the theoretical minimum. Addition of an inert gas to the flowing liquid produced a pronounced lowering of the heat transfer coefficient. After some 1400 hr operation, deposits mainly of Na<sub>2</sub>O occurred throughout the apparatus. It is shown that such deposits could be an important factor in depressing the heat transfer coefficient. It is not claimed, however that this is the only or principal factor. Other possibilities are commented upon. General operating experience is also described. The experiment included an investigation of the metallurgical changes occurring in a dynamic Na in stainless steel system and the results are compared with static controls.

NSA 12:5952

5.300 THE REACTION OF MOLTEN METAL WITH WATER. PROGRESS REPORT FOR JANUARY 1 THROUGH JANUARY 31, 1957  
Feb. 13, 1957, 7 p. (AGC-AE-34; AGC-L2914-23).

Explosion dynamometer tests were performed on 10g samples Zr from 3550 to 4670°F, 9g samples of NaK at 120°F, 9g samples of stainless steel at 4120°F, and Al at 2050°C. High-pressure high-temperature corrosion-rate tests were performed on Zircaloy-2 wire in steam at 1000 to 1200°C.

5.300 METALLURGICAL INVESTIGATIONS OF SODIUM HEAT TRANSFER RIG,

Ward, A. G., and Taylor J. W.  
(Gt. Britain Atomic Energy Research Estab.) Harwell, Berks, England) AERE-M/M-148 18 p. Feb. 1957

A study was made of the attack of stainless steel and Ni by Na, both oxygen-free and contaminated, at temperatures in the range 300 to 600 C in static and dynamic tests. A number of miscellaneous metallurgical investigations on components taken from a stainless steel/Ni double annulus heat exchanger rig are also reported. Under the conditions of test, stainless steel of the 18 wt. % Cr-8 wt. % Ni type containing free carbide, undergoes considerable attack, both in static and dynamic tests in Na normally free from and also heavily contaminated with O<sub>2</sub>. From the evidence available, it is suggested that the mode of attack consists of a decarburizing action which proceeds intergranularly and modifies the spheroidal carbide in the affected region by diffusion of this phase into the matrix. Under similar test conditions Ni undergoes no detectable corrosion even at the highest temperature. It is recommended that prior inspection be carried out on stainless steel for use in systems containing Na at temperatures above 300 C, to ensure that the steel specification has been fulfilled and, that the material is devoid of free carbide.

AD 256 511



- 5.300 ATTACK OF UNSTRESSED METALS BY LIQUID MERCURY  
J. F. Strachan and N. L. Harris, J. Inst. Metals 85, 17-24 (1956)  
(Paper No. 1715)

The solubilities and weight losses in the absence of air at room temperature of most of the metallic elements in static liquid Hg were determined, usually to 0.001%, by chemical analysis of the solutions and by weighing the specimens. The solubilities show a periodic relationship with the atomic number, and there are indications that this can be related to the inner electronic shell structure. In general, the solubilities of the B sub-group elements exceed those of the true metals, while this latter group the transition metals show the lowest values. When attack occurs, it involves wetting, surface amalgamation, solution and occasionally combination and intergranular penetration. Oxidation brought some metals of solution in Hg and led to ambiguities. Exposure to air can result in a form of mass transfer. No significant changes occurred in the mechanical properties of Fe, Mo, some steels, and Ni alloys after 2000 hrs in Hg at 500°. Ni suffered a decrease in maximum stress, yield stress, and elongation of about 50%. Severe cavitation erosion of metals and alloys, normally resistant to Hg, occurred at room temperature on the application of 30 kc/sec ultrasonic vibrations.

CA51-981h

- 5.300 Solubility of Sodium Monoxide in NaK  
Rodgers, S. J. and J. W. Mausteller  
Mine Safety Appliances Company, Callery, Penna. Technical Report  
No. 47 Contract NObs-65426. March 15, 1956. 9p.

The concentration of oxygen (added as Na<sub>2</sub>O) in NaK-24 (24 wt.% potassium) and NaK-44 was studied as a function of temperature. Oxygen concentrations are higher for higher temperatures. Curves are presented for oxygen concentration versus temperature and potassium content for NaK-24, NaK-44 and NaK-78. Up to 550°F the oxygen concentrations are independent of potassium content of the sodium, but above 550°F the curves diverge to reach oxygen saturations at 1000°F of 0.20, 0.15, 0.085 and 0.050 wt. % O<sub>2</sub>, respectively, for sodium, NaK-24, NaK-44 and NaK-78. These data can be applied to the problem of oxide precipitation by a leak from a third-fluid NaK system to a sodium system high in oxygen content. Below 0.010 wt. % O<sub>2</sub> in the sodium there would be no problem. Above this value precipitation would depend on the potassium content, temperature, and oxygen content, but the effect would be of little consequence in a well-designed sodium system.

- 5.300 NP-7410  
Plugging Leaks Between Water and Third Fluid System (Hg)  
Rodgers, S. J. et al.  
Mine Safety Appliances Co., Callery, Pa.  
Memo Report 92, September 29, 1955, 16p.  
Contract NObs-65426

An investigation was made of sealing methods for leaks between water (or steam) and mercury systems. Leaks simulating tube-to-tube sheet joint cracks were successfully plugged in > 1 hr by adding a commercial boiler sealant (Leakure) or an Fe-Fe<sub>2</sub>O<sub>3</sub> mixture to the water side. Addition of 1 wt. % magnesium + ~ 1 vol. % Leakure to the mercury system gave plugs in either steam or water leaks. Operating conditions were 500 psig (465 F) on the water side and ~ 300 psig 500 F on the mercury side. Pressures were alternated in some cases. Plugs held 500-800 psi differential pressures both at operating water conditions (atmospheric pressure on mercury side) and at room temperature (auth).

NSA 13:11851

- 5.300 KAPL-M-HFK-3  
HYDROGENOUS LOOP: WATER INJECTION TEST SDT-3 (on) RUN NO. W.1.-1  
H. F. Karnes. Sept. 12, 1955. 15p

Six grams of H<sub>2</sub>O were injected into the 1-inch hydrogenous loop at a temperature of 500°F. The pressure rise within the loop was more than 17 psi for at least 3/4 second and then decreased to 7.5 psi. Approximately 10% of the injected hydrogen was collected as gas in the surge tank. The balance is assumed to be in the form of NaOH and NaH. The plugging temperature of the Na increased from less than 300°F to 630°F after injection. Although the loop temperature was approximately 500°F, no flow restrictions were noted in the circulating system until flow was diverted to the plugging section. Cold trapping was successful in reducing the saturation temperature to 310°F. Hydrogen analysis of the Na confirmed the relative changes in plugging temperatures.

- 5.300 KAPL-M-NGM-2  
Knolls Atomic Power Lab., Schenectady, N. Y.  
Distribution of Uranium and Uranium Oxide in Liquid Metal Thermal Convection Loops by Mills, N. G. and R. F. Loenig. Jan. 23, 1951.  
Decl. March 9, 1957. 12p. Contract W-31-109-Eng-52.

Two tests were performed in Na thermal convection loops to obtain on indication of (1) where U or UO<sub>2</sub> would deposit in the SIR system in the event of a fuel pin failure and (2) how the dispersed fuel could be removed. It was also hoped that the results might apply as well to fission products since they appeared to accompany U in the experiment.

NSA 11:12564

- 5.300 See Also: 1.400, 11.410, 3.140, 3.400, and 4.311.

#### 5.400 FLUID FLOW AND HEAT TRANSFER PARAMETERS

- 5.400 CHEMISTRY AND CHEMICAL ENGINEERING DIVISION  
O. E. Dwyer and R. H. Wiswall (BNL-731 (p 18-46))

Heat transfer coefficients for Hg and NaK were verified by loops.

NSA 17:2461

- 5.400 NUCLEAR REACTOR  
G. Young (To USAEC) U.S. Patent 3,071,527. Jan. 1, 1963.

. . . liquid metal coolant. (more on abstract).

NSA 17:10120

- 5.400 NASA TN D 1188  
GOVERNMENT - INDUSTRY CONFERENCE ON MERCURY CONDENSING on April 18, 1961, Pasadena, California, Published February 1962, 162 p.

Some of the specific topics discussed were gravity effects and ground testings; test apparatus and measuring techniques; prediction of pressure drop; flow stability; physics of condensing; and effect of non-condensable gases. (AGN Lib. 2-752)

NSA 16:14354

- 5.400 AN-764  
MATERIAL PROBLEM AREAS IN LIQUID METAL COOLED SPACE POWER REACTORS - BRIEFING CHARTS. Aerojet-General Nucleonics, San Ramon, Calif.  
November 1962.

5.400 COLLOIDAL ELECTROHYDRODYNAMIC ENERGY CONVERTER

A. Lucile Cox  
(Ion Physics Corp., Burlington, Mass.)  
ARS Preprint No. 2559-62. New York, American Rocket Society,  
1962. Prepublication Copy. 10 p.

The colloidal electrohydrodynamic energy converter described changes the thermal energy of a slightly ionized superheated vapor to directed kinetic energy, then to high voltage electric energy. Performance of Hg, K, Na, and Li as working fluids is described.

NSA 17:9122

5.400 ALKALI METAL TWO PHASE HEAT TRANSFER FOR SPACE POWER - PRESENT STATUS

R. D. Brooks and S. G. Sawochka (General Electric Co., Cincinnati) ARS Preprint No. 2547-62. New York, American Rocket Society, 1962. Prepublication Copy. 27 p. \$1.00

An investigation is made of two-phase heat transfer and fluid flow characteristics in alkali metals. The theory and experimental data related to boiling and condensing are reviewed. Nucleate boiling data obtained in flat-plate pool boiling experiments with K are correlated with several relationships. A model of film boiling based upon the Prandtl mixing length concept is derived. Forced-convection boiling data in tubes are observed. Heat fluxes up to 600,000 Btu/hr-ft<sup>2</sup> are achieved in stable nucleate boiling. Data for condensation of K is also presented. Both forced and natural convection results show poor agreement with the Nusselt condensing correlation. Possible mechanisms for this discrepancy are postulated, and an empirical relation of results is presented. Flow stability for two-phase flow is briefly discussed. Analogy methods of analysis using water are noted. Typical instability observations for a boiling liquid metal loop are presented and the method of correction indicated.

NSA 17:8337

5.400 CONDENSATION OF METAL VAPORS DURING RAPID EXPANSIONS

P. G. Hill, H. Witting, and E. P. Demetri (Northern Research and Engineering Corp., Cambridge, Mass.) Preprint Paper No. 62-WA-123. New York, The American Society of Mechanical Engineers, 1962. 12 p. \$1.00. Paper from the Winter Annual Meeting, New York, November 1962.

A study was made of the condensation of metal vapors in nozzles, using the liquid drop nucleation theory, to predict the incidence of condensation and its effect on the properties of the fluid stream. The theory, which has been verified by accurate experimental data on skam, predicts that in the absence of charged particles, initially saturated Hg vapor, for example, is very reluctant to condense in a nozzle. On the other hand, the vapors of Na, K, and Rb should condense very readily. In each case the typical size and growth rate of the condensed drops are so small, that significant slip between vapor and liquid phases is very unlikely to develop. The nucleation process is rapid so that equilibrium is approached quickly. In reasonably long nozzles, it may be quite in order to realize the transition between supersaturated and equilibrium states as a step change.

NSA 17:8345

5.400 HEAT TRANSFER THROUGH MOLTEN MATERIALS

Inco Corrosion Reporter, v. 9, no. 2, Oct 1962, 13p.

Mechanism of liquid metal corrosion at high temperatures and under pressure in nuclear reactors as a function of solution rate and solubility limit of the solid metal in the liquid. Advantages and limitations of liquid metals as heat transfer media and use of 18-8 stainless steel with Na and NaK and Ni alloy Inor 8 with fluoride salt mixtures. 5 refs.

- 5.400     REACTION OF CONSTRUCTION MATERIALS WITH LIQUID METALS  
Nikitin, V. I., Teploenergetika, No. 2, 90-2 (1962) In Russian.

The utilization of liquid metals (sodium, potassium, and their alloys, bismuth, and lead) as reactor coolants was analyzed, and the mechanism of their reaction with construction materials was studied. The properties of coolants and construction materials, the temperatures and temperature gradients in the system, the rate of flow, and the presence of admixtures are discussed. The corrosion factors for bismuth and lead depend on their affinity to simple diffusion while for sodium and potassium, corrosion depends mostly on the amount of oxygen present. A table is included of maximum permissible temperatures for various construction materials, showing not more than 0.012 mm corrosion after 1000 hr, in molten sodium and lithium. (R.V.J.)

- 5.400     HEAT TRANSFER IN SODIUM-POTASSIUM ALLOY  
Baker, R. A. and Sesonske, Alexander (Purdue University,  
Lafayette, Indiana) Nuclear Sci. and Eng., 13; 283-8 (July 1962)

To provide heat transfer data of high precision for NaK heat exchange systems, a NaK heat transfer loop was designed to minimize experimental errors and yield results with a high degree of reproducibility. Average heat transfer coefficients were determined for both tube and annulus in a horizontal, concentric-tube, NaK (56% K)-to-NaK exchanger. The results after correction for entrance effects were described by the following empirical relations:  $N_{Nu} = 6.05 + 0.0074 N_{Pe}^{0.95}$  (tube); and  $N_{Nu} = 0.80 (d_2/d_1)^{0.3} [5.12 + 0.0296 N_{Pe}^{0.785}]$  (annulus), where  $N_{Pe}$  was the Peclet number and  $d_1$  and  $d_2$  were the inner and outer diameters of the annulus respectively. No distinction was found between the Nusselt moduli ( $N_{Nu}$ ) measured at uniform heat flux and those measured at variable heat flux. No change in the experimental Nusselt moduli was observed when the oxide content was varied between 0.0025 and 0.006 wt % oxygen. (auth)

- 5.400     AD-282370  
INVESTIGATION OF LIQUID METAL BOILING HEAT TRANSFER. QUARTERLY  
PROGRESS REPORT NO. 3 on PHASE 2A  
Balzhiser, Richard E., Colver, C. Philip, and others.  
July 1962. Michigan U. Coll. of Engineering, Ann Arbor

Potassium will be boiled from the outside of a 3/8 in. OD Haynes-25 tube at temperatures up to 2000°F and heat fluxes of 10 to the 6th power Btu/hr sq ft. This study is intended to obtain experimental data for the nucleate boiling of potassium at fluxes near the critical. The effect of pressure on the critical flux will be investigated. Film boiling studies employing potassium as the test fluid and sodium as the heating fluid will be conducted. Boiling will occur from a 0.200 in. Nb-1% Zr disk in a 1 in. Nb-1% Zr tube. A forced circulation liquid metal loop will circulate potassium at liquid flow rates up to 2 gpm. The maximum fluid temperature in the loop will be 1800°F. Potassium will be preheated to various qualities using clamshell heaters. Condensing sodium is used to boil the potassium in the test section. Fluxes of up to 10 to the 6th power Btu/hr sq ft are anticipated. Two phase flow studies will be conducted as a part of the forced circulation investigation. Pressure drop and void fraction measurements will be made for different qualities and flow rates. Loop instrumentation will be used in conjunction with the pool boiling studies. Agravic studies with mercury are scheduled. Studies will be from 1 - 20 g's with the liquid level varied to insure uniform pressures at liquid-vapor and liquid-solid interfaces. (Author)

- 5.400 AD-275147  
INVESTIGATION OF LIQUID METAL BOILING HEAT TRANSFER. QUARTERLY  
PROGRESS REPORT, No. 2 ON PHASE 2.  
Balzhiser, Richard E., Barry, Robert E. and others  
Michigan U. Coll. of Engineering, Ann Arbor, Michigan.  
April 1962, 16p., illus. Report No. 04526-4-P.  
Contract AF 33(616)8277. Unclassified.

Experimental equipment specifications are being completed for the study of quality and flow rate effects on heat transfer coefficient of boiled K in a forced circulation loop. Pressure drop and void fraction measurements will be made in a second test section to study 2 phase flow behavior with metallic fluids. A pool boiler will be used to study pressure effects and to increase the temperature and flux levels beyond the 1800 F and 10 to the 6th power Btu/hr-sq ft anticipated in the loop. Film boiling of K will be studied using condensing Na or La as a heat source. A Nb vessel will be used thus making it possible to increase the range of surface temperatures. Initial agravic experiments will utilize Hg pool boiling from a stainless surface with normal accelerations up to 20 g's. (Author)

- 5.400 LIQUID METAL HEAT TRANSFER IN NUCLEAR POWER REACTORS  
Friedland, Aaron (Atomic Power Development Associates, Inc.  
Detroit) Preprint Paper No. 90. New York, Engineers Joint  
Council, 1962, 26 p.

The status of liquid metal heat transfer studies is briefly reviewed. The sodium cooled Enrico Fermi Fast Breeder Reactor is described, with emphasis on the aspects of design and operation relating to heat transfer. (46 references) (auth)

- 5.400 ETUDE D'UN ECHANGEUR NaK-EAU EN REGIMES PERMANENTS ET TRANSITOIRES  
(The Study of a NaK-Water Exchanger in Steady and Transient States)  
(CEA-2173), List, D. and Schwal, B.  
(France. Commissariat a l'Energie Atomique. Centre d'Etudes  
Nucleaires, Saclay). 1962. 40p.

In a study on a NaK-water heat exchanger, the temperature variations, in the transient states, along the metallic wall separating the two fluids were examined. The basic equations (partial differential equations) are established and transformed into a differential equation system for which the various coefficients are calculated. These equations can be set up on an analogic computer for use in exchanger behavior studies. The steady states of the exchanger are studied first and it is then submitted to various types of perturbations. (auth)

- 5.400 NASA TN D 1188  
SUMMARY OF MERCURY CONDENSING WORK. Presented at the Government -  
Industry Conference on Mercury Condensing. April 18, 1961.  
J. Neustein and L. Hays, Electro-Optical Systems Inc.

The compound loop which is used for both direct and indirect condenser investigations is described, components discussed, and results tabulated.

- 5.400 NASA TN D 1188  
AERONAUTICAL SYSTEMS DIVISION PROGRAMS IN MERCURY CONDENSING  
Presented at the Government - Industry Conference on Mercury  
Condensing. April 18, 1961. Lt. Lloyd M. Hedgepeth

The programs briefly discussed are: Solar Power Unit Demonstrator (SPUD), Radiator Condenser for Space Environments, Design and Testing a Spray-Type Condenser for Zero-Gravity Operation, and Orbital Force Field Boiling and Condensing Experiments (OFFFACE)

5.400 ASD-TR-61-594

LITERATURE SURVEY ON LIQUID METAL BOILING FINAL REPORT - PHASE I

Balzhiser, Richard E., Clark, John A., Colver, C. Phillip, Huckle, Edward E., Merte, Herman Jr., Smith, Lowell R., and Teller, Andrew S. (Michigan University, Ann Arbor, College of Engineering) December 1961. Contract AF 33(616)-8277. 157p. (AD-270481)

A survey was made of information pertaining to the current status of liquid-metal-boiling technology. Material pertaining to boiling and two-phase flow phenomena are also included, and existing correlations for predicting heat transfer coefficients in the nucleate- and film-boiling regimes are summarized. Correlations which predict the critical heat flux (or burnout flux) are presented and compared with experimental data available. The use of liquid metals as fluids in space-oriented Rankine cycles is considered, and interfacial considerations of possible importance are cited and discussed. Particular attention is called to the solid-liquid interfacial energy and its importance in limiting heat transfer across the interface. A summary of physical properties for various liquid metals and water is presented along with 1191 references to books, reports, journals, and theses published from approximately 1930 to 1961. (P.C.H.)

5.400 NASA TN D 1188

MERCURY CONDENSER RESEARCH AND DEVELOPMENT. Presented at the Government-Industry Conference on Mercury Condensing, April 18, 1961. A. Koestel and J. J. Reinmann, TAPCO, April, 1961

Presented in this summary report are space condenser design criteria, basic design data, a description of condensing mercury research test apparatus with related analysis, and test results for both ground and zero-gravity tests. (AGN Lib. 2-752)

5.400 NASA TN D 1188

PRESSURE DROP IN TWO-PHASE FLOW. Presented at the Government - Industry Conference on Mercury Condensing. April 18, 1961. C. Baroczy and J. Sells, A.I. April 1961

Presents an attempt to determine a better method of correlation of the pressure drop data, and to obtain additional condensing pressure drop data. The second activity that is currently being undertaken is to obtain additional condensing pressure drop data of greater accuracy.

5.400 HYDRODYNAMIC STUDY OF BURNOUT IN BOILING

Report No. 17. Kinich Torikai (Japan Atomic Energy Research Inst., Tokyo) Jan 1961. 48p.

The burn-out mechanism, by which a heating surface is melted down in the high-heat flux is the heat transfer coefficient is suddenly decreased, is investigated on the basis of hydrodynamic aspects. . . . In forced-circulation boiling, a semi-theoretical analysis was made and the equation of the maximum heat flux,  $q_{B.O.} = \mu_m \gamma P (\lambda/8)(1-A_v)$ , was obtained, under the assumption that burnout mostly occurs when forced circulation in boiling makes a kind of turbulent diffusion . . .

NSA 15:20826

5.400 HEAT EXCHANGE IN THE LAMINAR AND TRANSITION REGIONS OF A LIQUID METAL FLOW

B. S. Petukhov and A. Ya. Yushin (Moscow Inst. of Power Engr.) Koksady Akad. Nauk S.S.S.R., 136:1321-4 (Feb 31, 1961)(In Russian)

Experimental studies were made of heat transfer in the laminar and transition regions of forced mercury flow in an annular tube with constant thermal flux density at the walls. The hydrodynamics and thermal stabilization of the flow was analyzed. The scheme of the experimental installation is included. (R.V.J.)

NSA 15:15729

- 5.400 ANALYTICAL STUDY OF HEAT TRANSFER RATES FOR PARALLEL FLOW OF LIQUID METALS THROUGH TUBE BUNDLES: II  
Aaron J. Friedland and Charles F. Bonilla (BNL)  
A.I. Ch. E. Journal 7:107-12 (March 1961)

A theoretical analysis of heat transfer to liquid metals in parallel flow through a tube bundle. (More on the abstract)

NSA 15:13063

- 5.400 HEAT TRANSFER IN A TURBULENT FLOW OF LIQUID METAL  
V. I. Subbotin, et al., Atomnaya Energy., 10:384-6  
(Apr 1961)(In Russian)

The turbulent heat transfer coefficient, the ratio of E for liquid metals, and the effects of heat conductivity are determined. The turbulent heat transition distribution coefficient along the cross section of a tube is plotted for various Re numbers, and correlation curves of analytical and experimental data on the temperature field in heavy liquid metal are given.

NSA 15:27748

- 5.400 HEAT TRANSFER MEANS  
A. P. Fraas and G. F. Wislicenus (to USAEC) U. S. Patent 2,991,980.  
July 11, 1961

A heat exchanger is adapted to uniformly cool a spherical surface, equations for the design of a spherical heat exchanger having tubes with a uniform center-to-center spacing are given. The heat exchanger is illustrated in connection with a liquid-fueled reactor.

NSA 15:22444

- 5.400 BOILING LIQUID METAL  
W. R. Gambill and H. W. Hoffman (Oak Ridge National Lab., Tenn.)  
Paper No. 1737-61. Presented at "Space-Nuclear Conference, May 3-5, 1961, Gatlinburg, Tenn." New York, American Rocket Society.  
24p.

Nuclear reactors utilizing a boiling liquid metal as the heat carrier provides a method for satisfying the auxiliary-power requirements of a space vehicle at a minimum expenditure in weight. Fundamental heat-transfer data (in particular burnout limitations) needed for effective design are not available, and recourse must be made to estimations based on data for other fluids. Such predictions are evaluated as they apply to K and Rb. It is concluded, in view of the wide disparity in the calculated peak-heat-flux values, that no reliable correlation exists. An additive technique that presupposes the independence of the boiling and convective heat-transfer mechanisms suggests that burnout flux levels with the liquid metals could be equivalent to those of water. Experiments on the subcooled boiling of water in swirl flow show that the peak heat flux is markedly increased over that attained with axial flow at the same pumping power. A similar advantage is indicated for K and Rb. In a bulk-boiling system swirl flow should be particularly effective in maintaining a desirable wetted-wall condition. An experimental program for securing information on burnout fluxes with liquid-metals is described.

NSA 15:23648

- 5.400 "Contact Thermal Resist in Heat Trans. to Liq. Metal,"  
O. P. Astakhov, V I. Petrov and O. S. Fedynskii. At Energy (USSR)  
11 255-7 (1961)

The disagreement with the Martinelli-Lyon theory of published exptl. data on heat transfer to liq metals is attributed to the presence of an addnl. thermal resistance at the heat exchanger material - liq. met. boundary prob caused by impurities. Data on heat trans should be presented not in rate coordinates but in resist. coordinates. In the case of Na(l) flowing in Cu tubes (8.6 mm dia) at an ave. no temp of 240°C, the thermal contact resist varies between  $0.48 \times 10^{-5}$  and  $0.28 \times 10^{-5}$  met<sup>2</sup>-hr °C/kcal. When vel. of Na inside tubes is 1.58 - 11 met/sec.

"Heat Transfer for Turbulent flow of a Liquid  
Metal in a Tube." V. I. Subbotin et al. AT Energ. (USSR)  
11 133-9 (1961).

The radial temp. distributed in a 30-mm Stainless Steel tube was detd. for alkali metals at Re of 16,200 and 24,700 and at heat fluxes of 40,000 and 39,500 kcal/sq m-hr. and for heavy metals at Re of 24,200 and 204,000 and at heat fluxes of 17,800 and 41,000 kcal/m<sup>2</sup>-hr. The wall temp. required to calculate the heat trans. coefficient was detd. by extrapolating the temperature profile of the liquid metal to the wall. The data fit the formula of Lyon (CA45 3205h) over a wide range of Pe of 100 to 12,000:  $Nu = 7 + 0.025 Pe^{0.8}$ . However, if the contact thermal resist. due to the oxide film on the heavy liq. metals is plotted as a function of Re. Chemical analysis shows that the content of oxide near the wall was about a factor of 10 greater than the content of oxide in the main stream of the heavy liquid metal.

CA 56 :11390h

5.400 LAMS-2531 Quarterly Status Report on Lampre Program for Period  
Ending February 20, 1961.

The LAMPRE-I project is summarized in terms of capsule development and production, sodium system, cover gas system, capsule charge, shielding, and fuel storage facility. The loading of the LAMPRE-I core was begun on January 20, 1961 with the sodium temperature set at 160°C. The reactor was brought to criticality on February 17, 1961. Operation of Sodium Test Facility was continuous except for six maintenance and inspection shutdowns resulting in 680 idle hours. The intermediate sodium heat exchanger, steam generating unit, centrifugal sodium pumps, sodium flow control valves, and gas-fired sodium heaters are discussed. Heat transfer test results are given for the various components. Research and development activities for the LAMPRE program are reported in the topics fuel and alloy program, container alloy development, direct contact core studies, development of liquid fuels, container materials for reactor fuels, and fuel reprocessing.

5.400 NAA-SR-7325  
SODIUM CONDENSING HEAT TRANSFER. AN EXPERIMENTAL STUDY OF ONE  
ASPECT OF SODIUM COOLED REACTOR SAFETY

Reed, G. L., and Noyes, R. C.  
(Atomics International, Div. of North American Aviation Inc.,  
Canoga Park, Calif.) Dec. 15, 1961. Contract AT(11-1)-Gen-8. 55p.

A problem of emergency heat removal in Na-cooled reactors is concerned with the condensing of Na vapors that might be generated as a result of a hypothetical loss-of-heat-sink accident. An evaluation, in which the Na vapor condensing in the restricted region below the loading face shield of the Hallam Nuclear Power Facility was made, to determine heat removal capability. Experimental determinations of condensing heat transfer rates in a model of this region were made. The primary resistance to heat transfer was found to be noncondensable gases present in the system. The gas (usually He) would be present because of its normal use as a cover gas in the core tank. A theoretical equation based on gaseous diffusion was derived, and the heat transfer rate is predictable provided the quantity of noncondensable gas is known. Further experiments were used to study the venting behavior of the gas space below the HNPF loading face shield during simulated accident conditions. These experiments provide information required to predict the quantity of noncondensable gas left in the system after a postulated accident and to predict associated heat transfer rates. Two venting methods were studied to determine the most efficient emergency venting procedure. It was found that if the region immediately below the top shield is vented, sufficient heat removal capability exists to condense all Na vapor that could be generated by afterglow heat. This would assure safety of the system by eliminating the possibility of any pressure buildup as a result of the postulated accident. (auth)



5.400 NUCLEAR ENGINEERING DEPARTMENT, PROGRESS REPORT. SEPTEMBER 1 -  
DECEMBER 31, 1960  
(BNL-659), May 1961. Contract AT(30-2)-Gen-16. 69p.

Heat transfer rates measured on the new loop for the flow of Hg through unbaffled rod bundles and results of an analytical study of heat transfer to liquid metals flowing in concentric annuli are reported. The operation of loops and capsules for testing materials in liquid metals is described.

NSA 15:30331

5.400 HEAT TRANSFER TO SODIUM AT SMALL VALUES OF REYNOLDS NUMBER  
M. S. Priogov. Atomnaya Energ. 8, 367-8 (1960) April 1  
(In Russian)

Heat transfer to sodium from round copper tubes (ID = 28 mm;  $\delta = 4$  mm) was measured in the Reynolds number range 17 to 416. The data, developed with the criterion  $Nu = f(Re)$  are plotted and correlated with published data. Agreement with the Martinelli-Lyon formula was obtained. The results do not confirm the postulations on sharp drops in heat transfer at small Re numbers.

NSA 14:15742

5.400 EVALUATION OF THE PERFORMANCE OF LIQUID METAL AND MOLTEN  
SALT HEAT EXCHANGERS  
M. M. Yarosh (ORNL). Nuclear Science and Eng. 8, 32-43 (1960)  
July

The data were correlated to permit predictions of the heat transfer and pressure drop performance of heat exchangers on ART.

NSA 14:19111

5.400 A NUCLEAR REACTOR  
(to USAEC) British Patent 837,769. June 15, 1960  
... Na coolant.

NSA 14:21160

5.400 NAA-SR-4873  
300,000 - KWE SGR NUCLEAR POWER PLANT OF CURRENT TECHNOLOGY  
J. Renard, et. al., (AI) Aug. 1, 1960. 148 p. Contract AT-11-1-  
GEN-8 OTS.  
... Na cooled power plant.

NSA 14:22600

5.400 HEAT TRANSFER BETWEEN MERCURY AND WATER FLOWING IN A CLOSELY  
PACKED ASSEMBLY OF RODS  
V. I. Subbotin, P. A. Ushakov, B. N. Gabrianovich, and A. V. Zhukov.  
Atomnaya Energ. 9, 461-9 (1960) December (In Russian)

The heat transfer to Hg and water from closely packed rod assemblies is analyzed. The temperature distribution at the heat exchange surface was measured, and the experimental installation, the treatment methods, and the analysis of the data are described. An approximate calculation method was developed for a certain group of tightly packed rods. (tr-auth)

NSA 15:6102

5.400 CIVILIAN POWER REACTOR PROGRAM, PART III BOOK 6, STATUS REPORT  
ON SODIUM GRAPHITE REACTORS AS OF 1959.  
TID-8518 (Bk 6) (AEC) 1960 57 p. OTS.

NSA 14:22615

- 5.400 BOILING VS. NON-BOILING LIQUID METAL COOLED REACTORS  
D. L. Cochran and K. E. Buck, Aerojet-General Nucleonics,  
San Ramon, California. Presented at the ARS Space Power  
Systems Conference, The Miramar Hotel, Santa Monica, California,  
September 27-30, 1960. Published in "Space Power Systems" -  
Progress in Astronautics and Rocketry. Vol. 4. Ed. by N. W.  
Snyder, Academic Press, N.Y. (1961)

The relative merits of boiling and non-boiling reactors for use in Rankine Cycle Space power plants over the power level range of from 1 to 20 Mw(e) are evaluated. A lithium-cooled fast reactor is most attractive for the non-boiling system, and a potassium-cooled boiling fast reactor is most attractive for the boiling system. Potassium is the cycle working fluid in each system. A turbine inlet temperature of 2000°F and shielding weights commensurate with manned applications are assumed. It is found that unless risks in reactor safety are accepted in the boiler reactor safety are accepted in the boiler reactor system, the non-boiling reactor system is more attractive in terms of size and weight. The weight savings resulting from such risks in the boiling system are only marginal and may actually be non-existent. The non-boiling reactor does not have the uncertainties caused by boiling in the core, and its development would be cheaper and less involved. Experimental data on boiling flow, heat transfer, and pressure drop are required to determine the relative desirability of the boiling reactor system.

- 5.400 TID-6045  
HEAT TRANSFER AND CRITICAL CONDITIONS IN NUCLEATE BOILING OF  
SUBCOOLED AND FLOWING LIQUIDS  
Yan-Po Chang, Univ. of Notre Dame, Notre Dame, Indiana  
1960 45 p. Contract AT(11-1)-785. OTS.

Liquid metals are considered as the heat transfer media (more on abstract).

NSA 14:16758  
CA 57:14906a

- 5.400 Kisilov, P. L., "Sodium and Sodium-Potassium Alloys as Heat  
Transfer Media for Steam Reheat and Technological Processes,"  
Teploenergetika, uv 10, 40-2 (1960)

Sodium and alloys of sodium and potassium may be considered as heat transfer media. Their physical properties are given. Published data cover the range of 0-700°C, and the data for higher temperature are obtained by extrapolation. Oxidation of the sodium must be prevented for two reasons: The oxides are corrosive and they may form solid deposits in the tube. Before filling the system it would have to be heated to a temperature higher than the melting point of sodium which is 97°C. This would not be required if the eutectic alloys of sodium and potassium were used, the melting point being below 20°C. A possible reheat circuit using sodium metal or sodium potassium alloy is illustrated schematically and the main characteristics are given. Various items of secondary equipment are described, including measurement of sodium oxide. Ordinary ferritic steels can be used in contact with sodium up to 459°C - 500°C and austenitic steel up to 800°C, provided that the oxygen content does not exceed 0.005% by weight.

NSA 15:24953

- 5.400 A MECHANISM OF TURBULENT HEAT TRANSFER IN LIQUID METALS  
N. Z. Arjer (Univ. of Alexandria, UAR (Egypt) and B. T. Chao.  
Intern. J. Heat and Mass Transfer 1, 121-38 (1960) Aug (In English)

A mechanism of turbulent heat transfer is proposed based on a modification of Prandtl's mixing-length hypothesis. Two expressions are obtained for the eddy diffusivity ratios for heat and momenta for fully developed pipe flow. One is for fluids of Prandtl number 0.6 to 15 and the other is for liquid metals. (More on the abstract)

NSA 15:1490

- 5.400 HEAT TRANSFER TO LIQUID METALS WITH VARIABLE PROPERTIES  
R. Viskanta and Y. S. Touloukian (Purdue Univ. Lafayette, Indiana)  
J. Heat Transfer 82, 333-40 (1960) Nov.

The problem of heat transfer to liquid metals with variable physical properties for the case of fully developed turbulent flow in cylindrical tubes of constant diameter was studied . . .

NSA 15:2746

- 5.400 HEAT TRANSFER TO MERCURY FLOWING TURBULENTLY IN AN ANNULUS  
V. I. Subbotin, P. A. Ushakov, and I. P. Sviridenko.  
Atomnaya Energ. 9, 310-12 (1960) October (In Russian)

With two-side heating of the annuli,  $d_2/d_1 < 1.09$  and equal thermal flows on both surfaces, heat transfer to mercury is about two-fold higher than in one-side heating . . .

NSA 15-2740

- 5.400 NUCLEAR ENGINEERING DEPARTMENT PROGRESS REPORT FOR SEPTEMBER 1 - DECEMBER 21, 1959  
(BNL-595) July 1960 (85 pgs) OTS

Heat transfer coefficients were obtained on three new test elements (circular heaters) in a 19-tube bundle through which Hg flowed turbulently and parallel to the tubes.

NSA 15:3773

- 5.400 ANALYTICAL STUDY OF HEAT TRANSFER RATES FOR PARALLEL FLOW OF LIQUID METALS THROUGH TUBE BUNDLES. PART 1  
O. E. Dwyer and P. S. Tu (BNL). Chem. Eng. Progr., 56: Symposium Ser. No. 30, 183-93 (1960)

Nusselt numbers were calculated for fully developed, turbulent, and parallel flow of liquid metals through staggered tube bundles by a method analogous to that of Lyon for flow of liquid metals inside circular tubes. (More on the abstract)

NSA 15:23641

- 5.400 SODIUM AND SODIUM-POTASSIUM ALLOYS AS HEAT TRANSFER MEDIA FOR STEAM REHEAT AND TECHNOLOGICAL PROCESSES  
P. L. Kirillov. Teploenergetika, No. 10, 40-2 (1960)

Na and NaK may be considered as heat transfer media. Their physical properties are given. Published data covers the range of 0-700°C and the data for higher temperatures are obtained by extrapolation. Reaction between Na and H<sub>2</sub>O would have to be prevented, but that between Na and steam is not so dangerous. Oxidation of the Na must be prevented for two reasons: the oxides are corrosive and they may form solid deposits in the tube. Before filling the system, it would have to be heated to a temperature higher than the melting point of Na which is 97°C. This would not be required if the eutectic alloys of Na and K were used, the melting point being below 20°C. A possible reheat circuit using Na metal or NaK is illustrated schematically and the main characteristics are given. Various items of secondary equipment are described, including, for example, measurement of Na<sub>2</sub>O. If the Na or NaK leaked into the furnace it would quickly burn, forming oxides and carbonates most of which would be removed with the flue gases. The Na does not come in contact with the water. The pressure of the steam is much higher than that of the sodium and if any leak occurred, it would be of steam into the Na. Various kinds of protective measures that would be required are mentioned. The use of electromagnetic pumps for metallic Na is recommended. Ordinary ferrite steels can be used in contact with Na up to 450° to 500°C; and austenitic steel up to 800°C, provided that the oxygen content does not exceed 0.005% by weight. (OTS)

NSA 15:24953

- 5.400 ANL-6269, Reactor Development Program Progress Report, Hilberr, N. (November 1960)

General research and development are reported on water-cooled and sodium-cooled reactors. Studies are also reported on reactor safety and nuclear technology (for preceding period, see Report ANL-6253).

- 5.400 Khabakhpasheva, E. M., Il'in, Yu. M., "Heat Transfer to an NaK Alloy in an Annulus," Atomnaya Energ. 9, 494-6 (Dec. 1960) (In Russian)

Heat transfer coefficients in annuli were determined by measuring the temperature at a considerable distance from the channel entrance. The experiments were carried out with two-side and one-side heat supplies to 2.5, 3.5 and 4.5 mm annuli. The Nusselt criterion for narrow annuli ( $d_1/d_2 \approx 1$ ) is about 25 to 30% less than for round tubes with identical Peclet values and is in good agreement with theoretical data. The Nusselt value for annuli (two-side heat supply at Peclet number exceeding 500) also agrees with theoretical data and exceeds by 1.3 to 1.5 folds the Nusselt number for round tubes. Consequently, the experiments confirm the theoretical postulation that the geometry of the channel and the means of heat supply influence heat transfer in heat carriers with small Prandtl numbers.

- 5.400 Liquid-Metal Investigation (GE-FPLD), J. W. Semmel, Jr., NASA TN-D-769, 1960

Na and K heat transfer loops,  $O_2$  determination in K, new alloys of Cb showing a greater strength than Cb-1Zr have been developed, and capsule corrosion tests.

NSA 15:13275

- 5.400 HEAT TRANSFER TO AN NaK ALLOY IN AN ANNULUS  
E. M. Khabakhpasheva and Yu M. Il'in. Atomnaya Energy. 9, 494-6 (1960) December (In Russian)

Heat transfer coefficients in annuli were determined by measuring the temperature at a considerable distance from the channel entrance. The experiments were carried out with two-side and one-side heat supplies to 2.5, 3.5, and 4.5 mm annuli. The Nusselt criterium for narrow annuli ( $d_1/d_2 \approx 1$ ) is about 25 to 30% less than for round tubes with identical Peclet values and is in good agreement with theoretical data. The Nusselt value for annuli (two-side heat supply at Peclet number exceeding 500) also agrees with theoretical data and exceeds by 1.3 to 1.5 folds the Nusselt number for round tubes. Consequently, the experiments confirm the theoretical postulation that the geometry of the channel and the means of heat supply influence heat transfer in heat carriers with small Prandtl numbers. (R.V.J.)

NSA 15:6104

- 5.400 Development Testing of Liquid Metal and Molten Salt Heat Exchangers  
McPherson, R. E., Amos, J. C., and Savage, H. W.  
Oak Ridge National Laboratory, Tennessee  
Nuclear Science and Engineering, 8, 14-20 (July 1960)

In order to investigate the design and fabrication problems inherent in compact, high-performance heat exchangers for aircraft nuclear propulsion applications, extensive development testing was done on bifluid (molten salt-NaK) heat exchangers and on liquid metal (NaK-air) radiators. These test units were prototypes of the heat transfer equipment which was to be used in the Aircraft Reactor Test (ART) at ORNL. Five bifluid test loops and one liquid metal test loop were used for performance and endurance testing of these components at simulated reactor operating conditions. The molten salt used was a ternary mixture of composition NaF 50 mole %, ZrF<sub>4</sub> 46 mole %, UF<sub>4</sub> 4 mole %. The NaK used was 56 wt % Na and 44 wt % K. A total of 47,000 hr of operation at 1200 to 1700 F was accumulated on 18 heat exchangers and 20 radiators. The program demonstrated that the compact heat exchanger geometries tested possessed the performance capabilities and mechanical integrity to meet ART design requirements.

NSA 14:19109

- 5.400     Development Testing and Performance Evaluation of Liquid Metal and Molten Salt Heat Exchangers  
MacPherson, R. E. and Yarosh, M. M.  
Oak Ridge National Lab., Tennessee  
CF-60-3-164 March 17, 1960

Development testing was done on prototype, bifluid (molten salt-NaK) salt exchangers and on liquid metal (NaK-air) radiators in support of the ANP program. The molten salt was a Na-Zr-UF<sub>4</sub> mixture, and the NaK was 56 wt % Na and 44 wt % K. Performance tests were conducted in prototypes of the main heat exchangers for the Aircraft Reactor Test. The flow range on the molten-salt side of the exchanger varied from Reynolds numbers of 1000 to 6000, and the NaK-flow operating range varied from Reynolds numbers of 15,000 to 200,000. Data were taken on 20-, 25-, and 100-tube bundles at start-up and after 500 and 1000 hr of operation. No deterioration of the salt coefficient occurred with time of operation. In general, the data were found to lie approximately 40% below the Dittus-Boelter line in the Reynolds range of interest. The effects of tube spacer arrangements on the unit performance were investigated. Pressure-drop data are presented for 1.75- and 0.5 MW Aircraft Reactor Test prototype radiator units.

NSA 14:24216

- 5.400     HEAT TRANSFER IN A LIQUID METAL FLOWING TURBULENTLY THROUGH A CHANNEL WITH A STEP FUNCTION BOUNDARY TEMPERATURE  
H. F. Poppendiek (Convair, San Diego, Calif.) March 1959  
55 p. (NASA-M-2-5-59W) Originally prepared as Report ZPh-015.

An analytical heat transfer solution is derived and evaluated for the general case of a turbulently flowing liquid metal which suddenly encounters a step-function boundary temperature in a channel system. Local Nusselt moduli, dimensionless mixed-mean fluid temperatures, and arithmetic-mean Nusselt moduli are given as functions of Reynolds and Prandtl moduli and a dimensionless axial-distance modulus. These solutions are compared with known solutions of more specific systems as well as with a set of experimental liquid-metal heat transfer data for a thermal entrance region.

NSA 13:15594

- 5.400     HEAT TRANSFER TO A TURBULENT FLOW OF LIQUID METAL WHERE HEAT LOAD IS DISTRIBUTED SINUSOIDALLY ALONG THE LENGTH OF PIPE  
V. I. Petrovichev and L. S. Kokorev (Inst. of Engr. Physics, Inst. of Thermophysics, Siberian Branch, Academy of Sciences, Moscow). Inzhener - Fiz. Akad. Nauk. Belorus S.S.R. 2. No. 12, 20-24 (1959) December (In Russian)  
(This is the translated abstract of NSA 14:25618)

The distribution of a thermal load along the length of a pipe wall has a considerable effect on the distribution of local coefficients of heat exchange if the heat transfer medium has a Prandtl number less than one. (more on abstract)

NSA 14:6417

- 5.400     HEAT TRANSFER DURING TRANSITION FLOW OF LIQUID METALS IN PIPES  
V. M. Deryvgin and O. S. Fedynskii (Kozhezhnovskii Inst. of Power Engineering, Moscow). Inzhener. - Fiz. Zhur., Akad. Nauk Belorus S.S.R. 2. No. 12, 3-10 (1959) Dec. (In Russian)

The "visual wetting" effect on heat transfer to liquid metals in a transition pipe flow is proved experimentally. The abrupt change in the heat transfer rate takes place at the hydrodynamic crises ( $Re \approx 2300$ ) when the surface of the heat exchanger is wet, but does not take place when wetting is absent. (More on abstract.)

NSA 14:6416

- 5.400     TURBULENT LIQUID METAL HEAT TRANSFER IN CHANNELS  
H. F. Poppendick (Convair, San Diego, Calif.)  
Nuclear Sci. and Eng. 5,390-404 (1959) June.

These solutions are compared with known solutions of more specific systems as well as with a set of experimental liquid-metal heat transfer data for a thermal entrance region. . . .

NSA 13:15599

- 5.400     EXPERIMENTAL FORCED-CONVECTION HEAT TRANSFER WITH ADIABATIC WALLS AND INTERNAL HEAT GENERATION IN A LIQUID METAL  
(thesis)(ORNL-2669)  
G. L. Muller, August 28, 1959. 108p. Contract W-7405-eng-26.  
\$2.50 (OTS)(submitted to Univ. of Tenn)

The investigation is an extension of the experimental and analytical work of H.F. Poppendick into the specific volume-heat-source heat-transfer problem of the flow of a liquid metal (Hg) in long, smooth, insulated pipes under internal heat generation conditions.

NSA 13:20497

- 5.400     BNL-4495  
LMFR BIMONTHLY PROGRESS REPORT, MARCH - APRIL 1959  
July 7, 1959. 96 p. OTS.

. . . Heat transfer coefficients, under improved test conditions, were measured for parallel flow of Hg through staggered tube banks.

NSA 14:4123

- 5.400     SODIUM COOLED GRAPHITE MODERATED NUCLEAR REACTOR  
(To North American Aviation, Inc.) French Patent 1,274,088.  
Sept. 11, 1961. Priority date Nov. 27, 1959, United States.

. . . the Na reactor coolant. (More on abstract).

NSA 17:9972

- 5.400     APPROXIMATE CALCULATIONS OF LIQUID-METAL HEAT TRANSFER  
IGIS-53 (RD/W)  
K. D. Voskresenskii and E. S. Turilina  
Translated by G. R. Taylor (U.K.A.E.A., Windscale) from p. 87-92 of "Teploperedacha i Teoriya Tepla," Academy of Sciences, U.S.S.R., Moscow, 1959. 8 p.

Approximate calculations are given of heat transfer during turbulent flow of liquid metals in smooth tubes.

NSA 14:11724

- 5.400     MND-P-2375  
SNAP I POWER CONVERSION SYSTEM DEVELOPMENT. Period Covered:  
February 1, 1957 to June 30, 1959. R. C. Biering, et. al.,  
TAPCO, (ER-4050) June 1960. For Martin Co. Contract AT(30-3)-217.

The system is designed to convert the thermal energy of a mercury Rankine cycle into electrical energy.     NSA 14:26034

- 5.400     MND-P-2376  
SNAP I POWER CONVERSION SYSTEM TURBINE DEVELOPMENT.  
Period Covered: February 1, 1957 to June 30, 1959. TAPCO  
D. C. Reemsnyder and E. M. Szanca June 1960.

A three-stage axial flow turbine with the first two impulse stages partial admission and the last stage full admission with a slight amount of reaction was selected.     NSA 14:26035

5.400 BNL-583  
NUCLEAR ENGINEERING DEPARTMENT PROGRESS REPORT FOR MAY 1 -  
AUGUST 31, 1959  
80 p. (OTS)

Additional heat transfer results were obtained for the case of parallel flow of Hg through staggered tube banks.

NSA 14:17642

5.400 THE EFFECT OF AN INTERNAL HEAT SOURCE ON THE HEAT TRANSFER  
COEFFICIENT  
S. S. Kutateladze, N.I. Ivashchenko, T. V. Zablotskaya  
Atomnaya Energ. 7, 253-4 (1959) Sept. (In Russian)

The influence of an internal heat source on the heat transfer coefficient is considered for the case where a liquid flows through a cylindrical tube; the effect of the entrance region is negligible.

NSA 14:1610

5.400 ORNL-1215  
HEAT TRANSFER AND PRESSURE LOSS IN TUBE BUNDLES FOR HIGH  
PERFORMANCE HEAT EXCHANGERS AND FUEL ELEMENTS  
G. H. Cohen, A. P. Frass and M. E. LaVerne. Aug. 12, 1952  
Decl. Oct. 9, 1959, 75 p. Contract W-7405-eng-26. OTS.

The heat transfer characteristics of one heat exchanger was determined with NaK. Includes a metallographic examination of heat exchanger after 3000 hr operation in NaK, and dynamic systems at approximately 1500<sup>0</sup>F or 850<sup>0</sup>C.

NSA 14:2218

5.400 SNAP I Mercury Boiler Development, January 1957 to June 1959  
Jicha, John and Keenan, James J.  
Martin Co. Nuclear Div., Baltimore  
MND-P-2309. June 1960, 102p. Contract AT(30-3)-217

The mercury-boiler development program was undertaken to develop a system that would utilize the heat of radioisotope decay to boil and super-heat mercury vapor for use with a small turbine-generator package. Through the use of a Rankine cycle, the mercury vapor can be provided continuously to power a turbine-driven alternator and produce electricity for extended periods of time. This mercury boiler and the related power-conversion system was planned for a satellite that would orbit the earth. This system design and development program was designated as SNAP-I. Development of the mercury boiler is described and a chronological description of the various mercury-boiler concepts is presented. The applicable results of an extensive literature survey of mercury are included. The mercury-boiler experimental-test-program description provides complete coverage of each experimental boiler and its relation to the system design of that period. A summary of all mercury boilers and their final disposition is also given. NSA 15:13463

5.400 THE COOLING PROPERTIES OF A LIQUID. V. A. Krivoukhov,  
A. I. Belousov, and T. L. Buyanova. Inzhener. - Fiz. Zhur., Akad  
Nauk Belorus S.S.R.2, No. 5, 15-19(1959) May (in Russian)

The cooling properties of liquids can be characterized by the rate of cooling of a standard model of an alloy with low heat conductivity. To increase the rate of cooling, a liquid must be chosen with maximum heat conductivity and minimum kinematic viscosity. The rate of cooling is a linear function of the flow velocity and increases sharply with a decrease in the temperature of the cooling liquid.

NSA 14:4422

- 5.400 JPRS-2397  
On the Thermal Processes in an Electromagnetic Induction Pump.  
J. Lielpeteris. Translated from Latvijas PSR Zinatni Akad. Vestis,  
No. 9, 91-100 (1959). 13p. OTS.

An analysis of thermal processes in an induction pump of planar construction was made. Basic schemes of the thermal processes are discussed. The heat exchange process between the liquid metal and the walls is discussed for pumps with forced cooling systems, with and without compensation for heat loss by the liquid metal, and for pumps without forced cooling. Calculations on steady and transient thermal processes were made.

NSA 14:11708

- 5.400 NP - tr - 642  
Liquid-Metal Coolants in Nuclear Reactors, Andrew, P.A.  
Kanev, A. A., Fedorovich, E. D., translated from  
a Russian publication, Leningrad 1958, 463 pp.

Information on the properties of liquid metals used as coolants in nuclear reactors is presented. Topics discussed include heat transfer in the liquid phase or during boiling and condensation, the interaction of liquid metals with structural materials, methods for removing impurities from liquid metals, and the peculiarities of design and operation of systems with liquid metals as coolants. The requirements to be met by heat transfer media used in nuclear reactors and ways to raise the efficiency of atomic power plants employing liquid metal coolants are outlined.

NSA 15:24538

- 5.400 STATUS OF LIQUID-METAL-HEATED STEAM GENERATOR TECHNOLOGY (BAW-1105)  
N. A. Bischel, Sept. 1958, 59 p.

An investigation was undertaken for a superior heat transfer and transport medium for use in atomic power plant steam generators. A list of the "ideal" properties of such a medium is presented.

NSA 13: 14057

- 5.400 LIQUID METAL RESEARCH IN THE INSTITUTE OF NUCLEAR RESEARCH IN  
1956-58  
(NP-tr-615)  
M. Pasek. Translated from Jaderna energie, 5:363-7 (1959) 20p.

The results are given of research work in liquid metals, done in the Institute of Nuclear Research of the Czechoslovak Academy of Sciences in 1956-1958. The results are focused mainly on tests of pumping and circulating of liquid metals in cooling systems, on studies of heat transfer, and on the measurements of flow and viscosity of liquid metals.

NSA 15:22640

- 5.400 A METHOD FOR THE DETERMINATION OF THE INTENSITY OF HEAT  
EXCHANGE IN MOLTEN METALS BY FREE CONVECTION  
A. I. Veynik. Trudy Inst. Energet. Akad. Nauk Beloruss. S.S.R.  
No. 3 62-7 (1957) (Translated from Referat. Zhur. Met., No. 10  
1958 p. 187)

NSA 14:297

- 5.400 Selection of Liquid-Metal Pumps by Hammitt, F. G. (Univ. of Michigan,  
Ann Arbor) Chem. Eng. Progr. 53, 249-53 (1957).

The design and development of large-scale, liquid-metal circulating pumps such as would be suited to application in nuclear power plants have been investigated. Fluid dynamic problems-cavitation and erosion damage to the structural components at the high relative velocities obtained in the pump impeller - were the particular concern.

CA 51:10139



J. E. Viscardi, Nuclear Development Corp. of America, White Plains, N. Y., Reactor Heat Transfer Conference of 1956. Collected Papers and Reports of a Conference Held at New York, November 1 and 2, 1956. (Issued in two books: (Bk. 1), 323p. and (Bk. 2), 318p.) November 1957.

Papers included in Book 1 cover: a general method of determining the total time interval of transients in linear systems, the basic equations describing energy flow and pressure drop relationships for transient coolant flow conditions in a nonhomogeneous plate-type reactor, rapid flow transients in closed loops, fast transient heat transfer in a clad element-stagnant  $H_2O$  system, transient heat conduction in solid cylindrical nuclear fuel elements, the response of a nuclear reactor coolant to power transients, a transient thermal analysis by means of analog computers, an analysis of fuel-plate temperature rise during a burnout transient, in-pile molten metal-water reaction experiments, pressure drop in rectangular channels at 2000 psia, flow redistribution due to boiling in a matrix, an investigation of burnout heat flux, nucleate and film boiling due to repetitive pulse heating of small wires immersed in  $H_2O$ , tubular vs. plate fuel elements: heat transfer and flow analysis, heat transfer within the cores of circulating fuel reactors, heat transfer and hydraulic characteristics of the SRE fuel element and heat transfer rates to cross-flowing Hg in a staggered tube bank. Papers included in Book 2 are on: heat transfer to Pb-Bi in turbulent flow in an annulus, pool-boiling heat transfer with Hg, heat transfer investigations of polyphenyl coolants, heat transfer in a radial spray chamber, the dependence of the heat transfer coefficient on the ratio of the heat fluxes from the walls of parallel plane flow channels, heat transfer and pressure drop characteristics of wire-coil-type turbulence promoters, an analysis of axial turbulent flow and heat transfer through banks of rods or tubes, heat transfer from parallel rods in axial flow, high-temperature heat transfer to a gas flowing in heat-generating tubes with high heat flux, the use of the Mach-Zehnder interferometer in heat transfer studies, compact tubular heat exchangers, and temperature and flow distribution in air-cooled reactors. Discussions are included from the burnout in natural and forced convection, heat transfer performance of reactor systems utilizing solutions, suspensions and slurries as fuel-bearing fluids, fused-salt heat transfer systems, transient boiling heat transfer and fluid flow characteristics, and analog and digital computer techniques useful in core heat transfer studies.

NSA 12:6195

Firman, E. C. et al. (United Kingdom Atomic Energy Authority, Research Group. Atomic Energy Research Establishment, Harwell, Berks, England) Experience Obtained on a Liquid Sodium Heat Transfer Rig 1954/1956. August 1957. 31 pages

Heat transfer data for Na flowing at moderately low Reynolds number in a double annulus heat exchanger are reported. The results qualitatively confirm the findings of coefficients well below the theoretical minimum. Addition of an inert gas to the flowing liquid produced a pronounced lowering of the heat transfer coefficient. After some 1400 hr operation, deposits mainly of  $Na_2O$  occurred throughout the apparatus. It is shown that such deposits could be an important factor in depressing the heat transfer coefficient. It is not claimed, however that this is the only or principal factor. Other possibilities are commented upon. General operating experience is also described. The experiment included an investigation of the metallurgical changes occurring in a dynamic Na in stainless steel system and the results are compared with static controls.

NSA 12:5952

THE LOS ALAMOS FAST PLUTONIUM REACTOR. E. T. Jurney, Jane H. Hall David B. Hall, Avery M. Gage, Nat H. Godbold, Arthur R. Sayer, and Earl O. Swickard. May 1954. Decl. Mar. 13, 1957. 144p. (TID-10048)

The Los Alamos Fast Plutonium Reactor is a low-power reactor built primarily to demonstrate the feasibility of a reactor operating on fast neutrons and to serve as an experimental facility. The operating power level of 25 kw produces a fast flux of approximately  $4 \times 10^{12}$  nvt. The reactive region consists of a lattice arrangement of metallic Pu fuel rods surrounded by normal U reflector material and cooled by flowing Hg. Experimental facilities consist of numerous fast neutron ports and a graphite thermal column.

- 5.400 EFFECT ON TEMPERATURES IN THE FAST REACTOR CORE OF VARYING DIMENSIONS AND SPACING OF TUBULAR FUEL ELEMENTS. L. Cross, June 6, 1955. Changed from OFFICIAL USE ONLY May 20, 1957. 27p. (FRDC/P-113; CF-5250)

An estimate has been made of the temperatures of cans, coolant and fuel on the axis of a core in the form of a 10-in. right cylinder. The coolant is 50/50 NaK and the power rating 60 Mw. The cans have a wall thickness of 0.02 in., the inner can being Ni and the outer Ta. Diagrams show the variation in these temperatures as the pitch of the elements, the minimum gap between them and the ratio of fuel to core volume are each varied in turn from a standard arrangement in which these quantities are respectively 1 in., 0.1 in., and 0.55 in.

- 5.400 Heat Transfer Rates to Cross-Flowing Mercury in a Staggered Tube Bank - II. C. L. Rickard, O. E. Dwyer, and D. Dropkin. p.297-315 of Reactor Heat Transfer Conference of 1956 Held at New York, November 1-2, 1956. John E. Viscardi, comp. November 1957. 635p. (TID-7529 (Pt. 1)(Bks 1 & 2))

As part of a continuing liquid metal heat transfer program at the Brookhaven National Laboratory, both local and tube-average heat transfer coefficients have been obtained for the flow of Hg normal to a staggered tube bank. The bank consisted of sixty 1/2-in. tubes, six wide and ten deep, arranged in an equilateral triangular array. The present paper presents results showing the effects of flow rate. Prandtl number, wetting, gas entrainment, and tube location on the tube-average coefficients. The angular variation of the local coefficient has not been considered here, owing to the fact that the values have not been completely calculated from the original data. The Hg results are compared with a few results obtained with water in the same equipment. The heat transfer runs cover the Reynolds number range of 20,000 to 200,000, whereas the water runs over the range 8,000 to 20,000. Pressure drop results for both water and Hg flow through the tube bank are also reported. The Hg coefficients for tubes in the interior of the tube bank are well represented by the equation.  $Nu = 4.03 + 0.228 (Pe)^{0.67}$ . 7 references.

- 5.400 ORNL-2431  
Oak Ridge National Lab., Tenn.  
Molten-Salt Reactor Program Quarterly Progress Report for Period Ending October 31, 1957. 47 p. Contract W-7405-eng-26.

Nuclear Calculations. Additional calculations were made of the nuclear characteristics of two-region homogeneous molten-salt converter reactors. Critical inventory calculations revealed that for a 9-ft.-diameter core the minimum inventory would be about 100 kg of  $U^{235}$ . Regeneration ratios were obtained as a function of inventory for a 600 Mw system, with Th concentration as a parameter. Gamma Heating of Core Vessel. It was estimated that for operation of the Reference Design Reactor at 600 Mw in a pure Ni core vessel 6 ft in diameter with 1 mole %  $ThF_4$  in the fuel, core gamma rays will liberate 13.4 w/cm<sup>3</sup> in core vessel<sub>3</sub> wall. Heating by gamma rays emitted in the blanket was found to be 0.97 w/cm<sup>3</sup>, and capture gamma rays originating in the wall were found to contribute 1.63 w/cm<sup>3</sup> to the heating. Heat Transfer Systems. One system being studied transfers heat from the fuel salt to a coolant salt to Na to water, and the other system substitutes Hg for the Na. The electrical output for a 600 Mw (thermal) reactor would be 258.6 Mw with the Na system, and 295.8 Mw with the Hg system.) Metallurgy. Investigation of container materials for molten salts for reactor operation up to 1300°F reveals that Ni-base alloys are the most suitable. Since the corrosion resistance, and high temperature strength of Inconel are marginal, INOR-8 has been developed and its properties are being studied. Radiation Damage. An In-pile INOR-8 thermal convection loop for operation in the LITR with a  $BeF_2$ -LiF- $UF_4$  fuel mixture is described. Chemistry. Phase diagrams are presented for the LiF- $BeF_2$ , NaF- $BeF_2$ , NaF-LiF- $BeF_2$ , LiF- $BeF_2$ - $UF_4$ , NaF- $BeF_2$ - $UF_4$ , LiF- $ThF_4$ , and NaF- $ThF_4$  systems. An analysis of the corrosion mechanism of fluoride fuels contained in Inconel or INOR-8 alloys indicates that Cr deposition will not result under anticipated conditions of the MSR.

NSA 12:5654

- 5.400 TEST RESULTS OF LIQUID METAL CLOSED CYCLE COOLANT SYSTEM.  
SUPPLEMENTARY REPORT NO. 1. R. C. Andrews and J. R. Betz. Nov. 15,  
1957. 23p. (MSAR-TR-321-12; D-143-941-035). For Bell Aircraft  
Corp.

NSA 12:13081

- 5.400 SUGGESTIONS FOR WORK ON DESIGN OF HEAT EXCHANGERS IN LIQUID  
METAL FUELED REACTORS  
C. L. W. Berglin  
June 1956 8 p. (AAEC/E-2) Atomic Energy Commission Research  
Establishment, Lucas Heights, New Smith, Wales, Australia.

A discussion is presented of the heat transfer film coefficient  
for the secondary coolant side of tubular exchangers.

NSA 13:12249

- 5.400 AD 256 511  
DESIGN, FABRICATION AND PERFORMANCE OF THE DUPLEX HEAT TRANSFER TUBE  
Mehring, R. J.  
(Knolls Atomic Power Lab., Schenectady, N. Y.) KAPL-1797, 60 p.  
(Sept. 28, 1956. Decl. Apr. 4, 1958)

The heat transfer characteristics and stress levels in duplex tube for  
heat exchangers are interdependent. This summary assembles into a single report  
the various studies of the heat transfer characteristics and stress analyses  
that have been made. The heat transfer characteristics discussed are those  
for boiling water, liquid metal, and metal-in-metal contact. Analyses have  
also been made of the fabrication and operating stresses. As a result,  
recommendations have been made regarding material properties, tolerances, and  
surface conditions of the tubular components, fabricating procedures, and  
operating precautions. Where areas of uncertainty still exist, tests have  
been recommended. This information is significant to the SIG Test Steam  
Generator Program, since this steam generator is to have duplex heat exchanger  
tubes.

- 5.400 EFFECT OF MERCURY AS A HEAT CARRIER ON STEEL IN POWER-GENERATION  
EQUIPMENT  
Gudtsov, Nikolay Timofeyevich, Gavze, and Mariya Nikolayevna  
Moscow, Izd-vo Akademii Nauk SSR, 148 pp. 2,500 copies, 1956
- 5.400 KAPL-M-FJM-1  
SUMMARY OF DUPLEX TUBE ANALYSES. F. J. Mehring. Sept. 28, 1956.  
Includes Appendices A through G. 73p.

The heat transfer characteristics and stress levels in duplex tubes  
for heat exchangers are interdependent. The various studies of the heat trans-  
fer characteristics and stress analyses are summarized. The heat transfer  
characteristics discussed are those for boiling water, liquid metal, and metal-  
to-metal contact. Analyses have been made of the fabricating and operating  
stresses. As a result of these various analyses recommendations were made  
regarding material properties, tolerances and surface conditions of the tubular  
components, fabricating procedures, and operating precautions. Where areas of  
uncertainty still exist tests have been recommended. This information is  
significant to the SIG Test Steam Generator Program, since this steam generator  
is to have duplex heat exchanger tubes.

- 5.400 KAPL-M-EDL-65  
SIG Rotating Plugs Test. R. A. Jacoby and A. P. Kokosa.  
Feb. 21, 1956. 159p.

The mechanical and heat transfer characteristics of the  
Mark A rotating plugs were investigated. The tests were conducted with static  
Na and without radioactivity. The results of the testing program indicated  
the desirability of improvement in the heat transfer characteristics and in  
sealing of the plugs. The need was also pointed up for improvement of the  
rotational characteristics that simulate the refueling operation of the  
rotating plugs. Developmental work was accomplished and the heat transfer,  
sealing, and rotational characteristics were improved.

- 5.400 Pool-Boiling Heat Transfer With Mercury. C. F. Bonilla, J. S. Busch, A. Stalder, N. S. Shaikhmahmud, and A. Ramachandran. p324-41 of Reactor Heat Transfer Conference of 1956 Held at New York, November 1-2, 1956. John E. Viscardi, comp. November 1957. 635p. (TID-7529(Pt. 1)(Bks. 1 & 2))

Hg was boiled on a horizontal low carbon steel plate at absolute pressures from 4 mm to 45 lb/in., liquid depths of 2 to 10 cm, heat velocities of 4,000 to 200,000 BTU/hr-ft<sup>2</sup>, and with and without wetting-agent additions. The nature of the boiling and the necessary temperature differential were observed. 13 references. Also in liquid metals technology. Part 1 of Chemical Engineering Progress Symposium Series (available in AGN-LIB C.1 3-689). No. 20-Vol 53:1957.

- 5.400 BNL - 2620  
Heat Transfer Rates to Cross-Flowing Mercury in a Staggered Tube Bank. R. J. Hoe, D. Dropkin, and O. E. Dwyer. 1956. 34p.  
Submitted for publication in Transactions of the ASME

An experimental heat transfer program has been underway for some time at the Brookhaven National Laboratory, the general purpose of which is to obtain and correlate heat transfer coefficients for liquid metals flowing outside of tube banks. This paper covers one phase of the program, i.e., the measurement of heat transfer coefficients for mercury flowing normal to a staggered tube bank. The factors studied were (a) linear velocity, (b) tube location in the bank, (c) circumferential variation of the local coefficient for a single tube, (d) type of contact, i.e., "wetting" vs. "non-wetting" and (e) pressure drop. The local heat transfer coefficient varies smoothly from a maximum at the forward stagnation point to a minimum at the rear stagnation point in the Reynolds number range 15,000-80,000, the magnitude of the variation corresponding to a factor of 4-5. The average heat transfer coefficient for a tube in the interior of the bank varies as the 0.52 power of the velocity for non-wetted tubes and 0.66 for wetted tubes. For tubes located in the interior of the bank, wetted tubes give heat transfer coefficients considerably greater than those for unwetted tubes, e.g., at a Reynolds number of  $5 \times 10^4$  they are 35% greater. For a tube located in the front row, the difference was found to be much greater, the corresponding figure being 65%. The lower coefficients obtained in the front row of the tube bank compared to those in the interior, for the non-wetted tubes, is in general agreement with results obtained with ordinary fluids. Tubes located at the side walls give coefficients about 20% below those for tubes located in the interior of the tube bank.

- 5.400 BNL - 337  
Liquid Metal Heat Transfer. p. 30 of Quarterly Progress Report for January 1 - March 31, 1955. (Unclassified Section): 61p.

The second phase of the program is now being undertaken for the purpose of extending the range and number of variables previously investigated and studying further the effect of "wetting." The experimental conditions which will be used are listed. The factors to be studied are: linear velocity; tube location; effect of angle on the local coefficients around the circumference of a given tube; type of contact, i.e., "wetting" vs. "non-wetting"; geometry; and Prandtl number. The experimental methods and equipment will be essentially the same as those used in the previous work.

- 5.400 HEAT TRANSFER CORRELATIONS FOR LIQUID METALS  
R. D. Brooks and S. F. Friedlander  
The Reactor Handbook, Vol. 2, Engineering, Ch. 2-3, p 277-86 (1955).

Covers Hg, K, Na, and NaK. (28 references)

- 5.400 NP - 5714  
Liquid Metal Technology. Final Report. (A review of the work from May 1949 to May 1954 with abstracts of reports issued).  
R. C. Werner. Mar. 29, 1955. 77 p. Contract N9onr-85801.

A final summary is presented of the various activities which have been carried out on liquid Na and NaK plumbing systems. Results on heat transfer, flow properties, corrosion tests, accessibility, Na cleaning, and tests on valves, bellows, pumps, etc. are included. Approximately half the report consists of abstracts of the various technical reports and memos which have been issued under the contract. (For preceding progress report see NP-5601.)

- 5.400 GENERATION OF STEAM FROM LIQUID AT HIGH HEAT FLUXES  
E. C. King and R. C. Andrews (Mine Safety Appliances Co., Callery, Pa.). Chem. Eng. Progr. Symposium Ser. 51, No. 17, 33-40 (1955).

The performance of specially designed double-wall stainless-steel tubes was compared with that of a single-wall tube in the generation of steam at high heat fluxes. Na-K alloy in the tubes was the heat-transfer medium. Heat was transferred at fluxes as high as 450,000 Btu/(hr.) (sq.ft.) at steam pressures between 113 and 1203 lb./sq.in. abs. The over-all heat-transfer coeffs. ranged from 412 to 1306 Btu/(hr.) (sq.ft.) (<sup>0</sup>F). Evaluation of the tube design and bond resistance was made and a method for calcg. the performance of such tubes is presented.

CA50-623i

- 5.400 REACTOR ENGINEERING AND SERVICES DIVISION. QUARTERLY REPORT (FOR) DECEMBER 1, 1950 THROUGH FEBRUARY 28, 1951. W. P. Bigler. Mar. 14, 1951. Dec1. Dec. 10, 1955. 29p. Contract W-31-109-eng-38.  
ANL-4596 \$4.80(ph OTS); \$2.70(mf OTS).

An electromagnetic pump, its head-capacity characteristics when pumping NaK, and its current supply are illustrated. The recommended building design for the Argonne Research Reactor is discussed. Heat transfer and fluid flow problems connected with D<sub>2</sub>O flow and the effect of the chilled water system on pile reactivity are discussed in some detail, as is pile control by water expulsion. Curves of heat production in U fuel rods after shutdown are given, measurements of the resonance integral of massive Th shapes are reported, and the status of an experiment on change in length of U metal under irradiation is summarized briefly.

- 5.400 NP-5751  
FINAL REPORT ON THE 1000 KW AIR COOLED, LIQUID METAL HEAT TRANSFER loop. R. A. Tidball, F. L. Mangold, S. N. Tower, and T. A. Ciarlariello. Aug. 16, 1955, 129p. Project NR-031-364. Contracts N9onr-85801 and NObs-65426, Technical Report No. 39.

A 1000-Kw liquid metal heat transfer system has been designed and operated at 1500<sup>0</sup>F. The system used sodium-potassium alloy to transmit heat from a gas fired furnace to an intermediate heat exchanger. Sodium was used to transmit the heat from the intermediate heat exchanger to an air heat sink. The maximum heat load on the system was 3,500,000 Btu/hr with the NaK temperature at the heater outlet of 1500<sup>0</sup>F. (See also NP-5491.)

- 5.400 CF-55-12-120  
THERMAL CHARACTERISTICS OF THE ART FUEL-TO-NAK HEAT EXCHANGER (ORNL) J. L. Wantland. Dec. 22, 1955. Dec1. Sept. 15, 1959, 32 p.  
\$6.30 (ph), \$3.00 (mf) OTS.

The results of this investigation are compared with the results from similar configurations by other investigators.

NSA 13:21426

- 5.400 KAPL-1367  
THEORY AND ENGINEERING APPLICATION OF A PRACTICAL THERMOELECTRIC ELECTROMAGNETIC (TEM) PUMP. Lewi Tonks. Aug. 1, 1955. 28p. Contract W-31-109-Eng-52.

Calculations show that thermoelectricity can have a practical power application to the electromagnetic pumping of liquid metal coolant through a nuclear reactor and its associated primary heat exchanger with the thermoelectric elements and circuit as an integral part of the exchanger. Here the basic theory of such a device is developed, including the parasitic circulation of current within each fluid metal channel, the varying temperature difference over the length of the exchanger, and the modification of theory consequent to having the fluid metal in pipes. Possible causes of instability are discussed and how to attack their analysis is indicated, but no analysis is made. The theory is applied to a specific engineering design.

- 5.400 NP-5752  
SODIUM PLUGGING OF VENT LINES  
E. C. King and V. K. Heckel  
Sept. 7, 1955. 11 p. Contracts N9onra-85801 and NObs-65426, Technical Report No. 42.

The distance sodium will travel in a copper or stainless steel pipe or tube of inside diameter between 0.180 to 0.622 in. can be calculated to within an accuracy of  $\pm 3$  ft from the equation:

$$S = (4 k_w d / k_w - 8.9 + 4 k_w d) (1020 d / 208 - T_a 18.08 d - 3059 / d - 0.1258)$$

where S is the distance of sodium travel in ft,  $k_w$  is the thermal conductivity of the tube wall in Btu/hr-sq ft-°F/ft, d is the inside diameter of tubing in in., and  $T_a$  is the ambient temperature in °F surrounding the tube, or the tube wall temperature.

- 5.400 CF-54-1-155  
INTERMEDIATE HEAT EXCHANGER TEST RESULTS  
(ORNL) B. M. Wilner and H. J. Stumpf  
Jan. 29, 1954. Decl. July 16, 1959, 35 p. Contract W-7405-eng-26  
\$6.30 (ph), \$3.00 (mf) OTS.

After 1680 hours at 1300°F and a power failure, the Na system shut down and was accidentally frozen.....

NSA 13:21425

- 5.400 NP ~ 5779  
Progress Report No. 30 for August and September 1955. W. J. Posey, ed. Oct. 11, 1955. 78p. Contract NObs-65426.

The results of tests on models of the Submarine Intermediate Reactor Mark B 3000-kw steam generators are reported. Data from steady state and cyclic operation have been obtained. The system has been shut down for cleaning, inspection, and repairs. Heat transfer with liquid metals flowing perpendicular to tube bundles is being studied, and some performance data are presented. An induction pump for liquid metals has been designed using the principle of the watt-hour meter. Tests are being performed to determine conditions influencing the low temperature wetting of surfaces with alkali liquid metals. The testing of valves and bellows for use in the SIR sodium system is described. Mockups have been constructed of the expansion tank and other components in the Mark B Na system. Tests are being performed on them to determine the effects of the use of impure N containing 2 vol.% O as a cover gas for the Na system. Methods of leak plugging are being studied for water to mercury leaks in the Mark A steam generating system. The removal of residual radioactive Na from a cooling system by means of Na flushes is being studied using  $Au^{198}$  as a tracer. The study of radiation hazards arising from leaks in a simulated contaminated water cooling system of a nuclear reactor is continuing. (For preceding period see NP-5739.)

- 5.400 HEAT TRANSFER II. Nuclear Engineering Course 1948-1949. H. A. Johnson.  
Feb. 24, 1949. Dec1. Nov. 22, 1955. 18p. (KAPL-532; MEMO-NEC-7).  
\$3.30(ph OTS); \$2.40 (mf OTS); Dep.(mc).

This report is a reprint of a lecture dated Feb. 5, 1948 by  
R. C. Martinelli.

The general theory of heat transfer due to fluid flow is discussed.  
The particular example of a fuel rod in a pile cooled by He and by Na is  
considered, including cases where flow area is not circular.

- 5.400 SODIUM COOLING OF NUCLEAR REACTORS. Werner Mialki. Atomkern-Energie  
3, 321-8(1958)Aug.-Sept. (In German)  
NSA 12:17793

- 5.400 ORO - 121  
Effect of Wetting on Heat Transfer Characteristics of Liquid Metals.  
Progress Report. R. M. Boarts, Harold Chelemer, and Bernard Hoffman.  
Feb. 1, 1954. 11p. Contract AT(40-1)-1310.

Progress is reported on the determination of the effect of wetting  
on the heat transfer characteristics of Hg by the use of additive wetting agents  
and variation of the heat transfer material. An effort was made to reduce the  
detachment effect of a modified Hg flow system (ORO-93) by operating under  
vacuum and by eliminating splashing of Hg in the reservoirs. The former  
showed little change, but a marked decrease in the detachment effect resulted  
from the latter change, indicating they were caused by entrained gas. Inves-  
tigations on a smaller scale showed that detachments like those above could be  
obtained by applying a vacuum to a glass vessel containing Hg which had been  
vigorously aerated. The density of aerated Hg was found to be as much as  
12% less than that of nonaerated Hg. The design of an apparatus to be used  
in measuring the temperature distribution in a steel-Hg-steel system is presented.

- 5.400 BNL - 270  
Quarterly Progress Report October 1-December 31, 1953.  
(Unclassified Section). 66p.

Liquid Metal Heat Transfer. The purposes of this project are to  
obtain (a) average film coefficients for individual tubes and (b) the variation  
of the local film coefficient with angle for individual tubes, for cross-flow  
of Hg in a staggered-tube bank. Reproducibility of results from run to run  
was poorer than expected, particularly for tubes located at or near the front  
of the tube bank. It appears that two pertinent factors are: (a) improved  
"wetting" with passage of time and (b) variability of the flow pattern after  
each start-up. By imbedding nine thermocouples on each test tube to avoid  
the necessity of rotating it, and by using temperature recorders, data-taking  
has been speeded up and the results are more precise. Some typical coefficient  
profiles for a tube located in the central portion of the tube bank are shown.  
The local coefficient for a given Reynolds number varies gradually from a  
maximum at the forward stagnation point to a flat minimum at the rear stagnation  
point. Generally, the value of the coefficient at  $180^\circ$  is about half that  
at the front. The average coefficient, for the tube as whole, is shown as a  
function of Reynolds number. The straight line drawn through the data has a  
slope of approximately 0.5.

- 5.400 Boiling and Condensing of Liquid Metals  
C. F. Bonilla and B. Misra. April 25, 1953. 9p.  
Contract AT(30-1)-1042. (NYO-3152). Dep.; Ind. Dep.

Additional runs have been made on the condensing of Hg vapor at  
atmospheric pressure and 330,000 to 650,000 Btu/hr-ft<sup>2</sup> on carbon-steel,  
stainless steel, and Ni, under wetting, semiwetting, and nonwetting conditions.  
The highest heat-transfer coefficient observed under any conditions was 2345  
Btu-hr-ft<sup>2</sup>-°F, for completely wetted Ni, which is less than 20% of the  
theoretical Nusselt value. Tests run in the presence of H and of N showed  
that traces of inert gas were not causing the decrease in coefficient. It  
is believed that the decrease is due to thermal contact resistance between  
the Hg and the condensing surface. This hypothesis is supported by earlier  
work on contact resistance.

QUARTERLY PROGRESS REPORT FOR JULY 1 - SEPTEMBER 30, 1953.  
UNCLASSIFIED SECTION). 57p.

Liquid Metal Heat Transfer. The objectives of this project are:

(1) determination of the average film-heat-transfer coefficient for individual tubes in a tube bank for crossflow of Hg therein; (2) determination of circumferential variation of the coefficient around an individual tube; and (3) determination of pressure drop across the tube bank. With the completion of an automatic liquid-level control system, reasonably good pressure-drop data have been obtained. Pressure drops are about 5% below those expected on the basis of data on oil at lower Reynolds numbers and data on H<sub>2</sub>O at higher Reynolds numbers. This is believed due to non wetting of the stainless steel tubes by the Hg. Data obtained on tubes in the interior of the lattice show that, in general, the local coefficient is a maximum at the front of the tube decreases to a minimum at the rear of the tube, the rear value being 50% of that at the front. At a Reynolds number of 20,000, h varied from about 3000 Btu/(hr)(ft<sup>2</sup>)(°F) at the front of the tubes to about 1500 at the rear. Presently available data show that the average coefficient varies as the 0.55 power of the Reynolds number. At a Reynolds number of 80,000 h is about 5000. Liquid Metal and Heat Mass Transfer in a Spray Column. Hg and dilute amalgams have been selected for a study of simultaneous heat and mass transfer in a spray column. These metals will be dispersed in a non-metallic phase. Water and various organic liquids are being considered for this phase. Originally it had been planned to find a component which would dissolve as a pure solution in both phases. Since nothing was found to satisfy this requirement, a reaction between a metal dissolved in Hg and an oxidizing agent will be utilized for the mass-transfer study. The major heat-transfer resistance is expected to be in the nonmetallic phase. Preliminary calculations indicate that the heat-transfer rate will be so rapid that difficulty in obtaining good data is anticipated.

5.400

RDB(W)-8054

Heat Transfer Experiments with Sodium

Hall, W. B. and Jenkins, A. E.

Windscale Works, Sellafield, Cumb., England

June 1953, 19p.

The theoretical approach to the problem of heat transfer in liquid metals is briefly reviewed. The difference between this approach and that used in the case of fluids with a high Prandtl number is due to the fact that the thermal conductivity of a liquid metal may be so high as to swamp the "eddy conductivity" in a turbulent stream. A description is given of experiments in which the heat transfer coefficients between two annuli each carrying a flow of sodium were measured. Since a direct comparison with results obtained with a circular tube is not possible, the results are in quite good agreement with the theoretical values given. In the course of the work it was found that there were significant variations in temperature around the annuli carrying the liquid metal in the heat exchanger. It is thought that these variations were due to a slight eccentricity of the exchanger tubes. An approximate theoretical treatment indicates that such variations are likely to be greater (when expressed as a fraction of the overall temperature difference) in the case of liquid metals than in the case of fluids with a high Prandtl number. In these experiments, where the heat flux was about 50 watts per cm<sup>2</sup>, the temperature variations were quite small, but if full advantage is taken of the liquid metal to obtain high heat fluxes, they might be so large as to produce serious thermal stresses and distortion of the heat exchanger.

NSA 13:12925

5.400

ORNL-1609 (del.)

AIRCRAFT NUCLEAR PROPULSION PROJECT QUARTERLY PROGRESS REPORT  
FOR PERIOD ENDING SEPTEMBER 10, 1953.

W. B. Cottrell, ed. Nov. 3, 1953, Decl. with deletions Nov. 12, 1959, 124 p. Contract W-7405-eng-26. OTS

. . . Na and K as coolants.

NSA 14:18646



5.400

RELATIONSHIPS BETWEEN POWER TRANSFERRED TO COOLANTS FROM CYLINDRICAL CONTAINERS AND  $\rho C_p$ , VOLUME FRACTION, AND  $V \Delta T$  OF THE COOLANTS.  
J. Bornstein and L. A. Berger. June 9, 1953. 11p. (KAPL-M-JB-11)

Nomographs and graphs are given which relate the power removed from cylindrical containers with the properties of various coolants such as Na, Li, NaOH, and H<sub>2</sub>O.

5.400

ANL-5060 (Del)  
REACTOR ENGINEERING DIVISION QUARTERLY REPORT [FOR] MARCH 1, 1953 THROUGH MAY 31, 1953. June 15, 1953. Decl. with deletions Jan. 17, 1957. 157p.

Power Breeder Reactor. Conceptual design studies for the Power Breeder Reactor indicate the feasibility of a contained primary coolant system in a package arrangement. One- and two-group calculations are presented in detail for preliminary PBR estimations. A technique for impregnating UO<sub>2</sub> with NaK has been developed. The resulting putty-type fuel was successfully extruded through a 3/8-in. hole. Data are presented on the fuel element design factors imposed by heat transfer and cooling limitations for fuel plates, pins, and spheres. Fission heat liberated in the PBR blanket was estimated to be 7.7% of the total core power. Design criteria resulting from this estimate are analyzed. Heat exchanger size for the transfer of 500 Mw of heat from Na to NaK has been calculated for the intermediate exchanger and for the NaK-to-H<sub>2</sub>O steam generator.

5.400

Heat Transfer to Mercury in Turbulent Pipe Flow. H. A. Johnson, W. J. Clabaugh, and J. P. Hartnett, July 1953. 63p. Contract AT-11-1-gen-10, Project 5, Phase II. (AECU-2627). Trans. Am. Soc. Mech. Engrs. 76, 505-11(1954); Dep. (mc)

Experimental heat-transfer results are presented for turbulent flow of nonwetting Hg in a 3/4-in., 18-gauge mild-steel tube with constant heat flux. The identical test heat exchanger developed for the previously reported investigation of molten Pb-Bi eutectic was used. This present investigation also includes a series of short duration tests for possible effects due to (1) secondary flow, i.e. vertical upward vs. downward heated flow, (2) the use of A as an alternate for a He atmosphere, and (3) the addition of Mg-Ti amalgam as a wetting agent. Heat-transfer tests with H<sub>2</sub>O preceded and followed those for Hg to establish continuing reliable performance of the test exchanger and its instrumentation. The results are correlated for the Peclet modulus range from 200 to 10,000 and are 4 to 10% lower than the previously reported values for Pb-Bi and 25 to 40% lower than the Martinelli-Lyon momentum theory. No difference in heat-transfer performance was noted for upward vs. downward flow or for the use of A as a replacement for He. No visible evidence of wetting occurred on the addition of the Mg-Ti amalgam, and no effect was found in the heat transfer.

5.400

ORO-100  
Effect of Wetting on Heat Transfer Characteristics of Liquid Metals; Progress Report. R. M. Boarts, Harold Chelemer, and Bernard Hoffman. July 31, 1953. 7p. Contract AT-(40-1)-1310.

The apparatus previously used (cf. report ORO-93) in the heat transfer studies has been modified to allow Hg delivery to the test section from an overhead reservoir 20 ft above the test section. This arrangement was chosen in order to eliminate any possible air entry sources present in the original system which might have caused the detachment phenomenon observed when a glass tube was used as a test section. However, this change resulted in an even greater amount of detachment. A series of photographs of the detachments was taken under several flow conditions. Studies are to continue to determine the nature and origin of this phenomenon and its effect on heat transfer coefficients. An investigation of contact angles between Hg and solid metal surfaces has been completed resulting in the formulation of two distinct types of wetting. Continued studies concerning interface phenomena are planned with the measurement of interfacial resistivities between mercury and solid metals under mercury flow conditions.

5.400 ORO - 93

Effect of Wetting on Heat Transfer Characteristics of Liquid Metals  
(thesis). W. K. Stromquist, Mar. 1953. 182p.

The effect of wetting on heat-transfer characteristics of liquid metals has been investigated by the use of additive wetting agents in Hg to permit direct comparison of wetting and non-wetting heat-transfer data in the same apparatus. The heat transfer system was of the single-tube type, directly heated by electric current in the tube wall. Low-carbon steel tubes of 3/8, 1/2, and 3/4-in. diameter were used as test sections, and pure Hg and 0.02% Na amalgams were used for tests under non-wetting and wetting conditions, respectively. An extensive series of tests was conducted over a range of Prandtl modulus from 0.017 to 0.022, a range of Peclet modulus from 88 to 19,400, and a range of Reynolds modulus from 5150 to 900,000. Results indicate that there is no steady inherent property of a non-wetted liquid-metal system that causes low heat transfer coefficients as compared with a wetted system, and that the erratic heat transfer data sometimes observed in non-wetted systems are due to random local detachment of the liquid from the tube wall. Similar erratic behavior may occur in wetted systems with rough walls. The detachment, with its corresponding erratic heat-transfer behavior, can be prevented by maintenance of sufficient pressure within the fluid, or more generally, by maintenance of a sufficiently high value of the Euler modulus (ratio of static head to velocity head).

5.400 ORO - 76

Effect of Wetting on Heat Transfer Characteristics of Liquid Metals;  
Quarterly Report for Period May 1 - July 31, 1952. R. M. Boarts,  
H. Chelemer, and W. K. Stromquist. July 31, 1952. 5p.

The purpose of this investigation is to determine the effect of wetting on the heat transfer characteristics of Hg, a typical liquid metal, by the use of additive wetting agents and variation of the heat-transfer-surface material. During this fifth quarter, the initial phase of the study of contact angles between Hg and steel under varying conditions has been completed (Kett's Thesis, June 1952) heat transfer data have been obtained under wetting and non-wetting conditions, and preliminary results of physical property measurements of pure Hg and dilute amalgams have been obtained. This work is summarized in report ORO-93.

5.400 ORO - 89

Studies of Interfacial Effects Between Mercury and Steel. Joseph  
J. Droher. June 1952. 92p. Contract AT-(40-1)-1310.

This investigation was undertaken to determine the effect of wetting on the heat-transfer characteristics of Hg by the use of additive wetting agents and by study of characteristics of heat-transfer-surface materials. Determination was made of heat-transfer data over a wide range of flow rates under both wetting and non-wetting conditions and a study was made of the characteristics of various solid metals in contact with Hg by examination of contact angles and electrical resistivity at the surface. A survey of the literature was made and information pertinent to these problems was collected. An apparatus was designed and constructed to measure the interfacial electrical resistance between a liquid and a solid metal surface. 89 references.

5.400 FAST REACTOR COOLANT COMPARISON. H. A. Brammer Dec. 15, 1952.  
Decl. Feb. 27, 1957. 11p. (LWS-24-701, CRD-R-17)

Calculations are made of the variation in critical mass of a fast reactor caused by several possible coolants. The coolants considered are Na, NaK, S, Pb, Bi, and Hg. Each system is calculated for U, Fe, Pb, and Bi reflectors. The derivation of the critical equation for a spherical core with an infinite reflector is included in an appendix.

- 5.400      ORO - 70  
Effect of Wetting on Heat Transfer Characteristics of Liquid  
Metals; Fourth Quarterly Report. R. M. Boarts and W. K. Stromquist.  
Apr. 30, 1952. 4p. Contract AT-(40-1)-1310.

The first phase of the study of electrical resistivity at Hg-solid metal interfaces has been completed, the measurement of contact angles of Hg against steel has been started, and the heat transfer system has been completed and placed in operation. In the study of electrical resistivity it was found that Cu always gave low interfacial resistivity, stainless steel always gave high resistivity, low carbon steel gave both high and low resistivities under apparently identical conditions, and that wetting was a sufficient but not a necessary condition for low interfacial electrical resistivity. No data are included.

- 5.400      ORO - 60  
Effect of Wetting on Heat Transfer Characteristics of Liquid Metals.  
Third Quarterly Report. W. K. Stromquist and R. M. Boarts. Jan. 31,  
1952. 6p. Contract AT-(40-1)-1310.

The purpose of this investigation is to determine the effect of wetting on the heat-transfer characteristics of mercury, a typical liquid metal, by the use of additive wetting agents and variation of the heat transfer surface material. Work during the first two quarters consisted of development and the start of construction of apparatus for the study of interface effects and determination of physical properties of mercury and diluted amalgams, and operation of a pilot-model heat transfer system. During the third quarter the interface studies have progressed rapidly and construction of the heat transfer system has been started. Preliminary measurements of electrical conductivity at mercury-solid metal interfaces indicate significant differences between wetting and non-wetting conditions with respect to conductivities at the interface. Tests have shown that newly created steel surfaces immersed in mercury are wetted without additive wetting agents. A device for measuring contact angles of mercury in controlled atmospheres at elevated temperatures has been built.

- 5.400      PROBLEMS IN THE USE OF MOLTEN SODIUM AS A HEAT TRANSFER FLUID.  
PART II. Leo F. Epstein and Clifford E. Weber, p.455-521 of  
NUCLEAR SCIENCE AND TECHNOLOGY. (Extracts from Journal of  
Metallurgy and Ceramics. Issue Nos. 1 to 6, July 1948-January  
1951). 67p. (TID-2501(Del);KAPL-362)) \$73.10 (ph), \$11.10  
(mf) OTS                      NSA 12:17306.

TID 3544

- 5.400      PROBLEMS IN THE USE OF MOLTEN SODIUM AS A HEAT TRANSFER FLUID.  
PART II  
C. E. Weber, L. F. Epstein, (KAPL) J. Metallurgy and Ceramics  
(AEC) 6:36 (1951)

- 5.400      NEPA-1377; BW-5204  
EROSION AND HEAT TRANSFER WITH LIQUID METALS: PROGRESS REPORT IV,  
MARCH 16-APRIL 15, 1950. H. G. Elrod, Jr. and Richard R. Fouse.  
Apr. 18, 1950. 9p.

Design and construction of an electromagnetic pump is discussed briefly. A charging unit for melting and supplying Li to various tests rigs and a simple inexpensive method of determining liquid levels at various points in the test apparatus are described.

- 5.400      NP - 1392  
REPORT I ON THE LIFE TESTS ON "FIGURE OF EIGHT" FLAT PLATE HEAT  
EXCHANGERS; TECHNICAL REPORT II. Robert A. Tidball. Jan. 25, 1950.  
Decl. Mar. 30, 1955. 18p. Contract N9onr-85801.

A figure-of-eight, heat-transfer system was constructed to measure changes in heat-transfer and flow characteristics of a system due to operation at elevated temperatures and using Na-K as the heat-transfer fluid. This system has been in operation one month. The pressure drop through the system decreased, and the heat-transfer coefficients increased slightly during this period. Heat-transfer coefficients are correlated in the manner presented by Harrison and Menke (Trans. A.S.M.E., 71, 797-803(1949).

- 5.400 PRELIMINARY HEAT TRANSFER-FLUID FLOW CALCULATIONS FOR THE KAPL REACTOR MAY 1949. R. W. Lockhart. Decl. Mar. 18, 1957. 146p. (KAPL-M-RWL-2(Rev.); Memo-RWL-2(Rev.))

Work performed during a two-year period (1946 to 1948) on the development of reactor cooling systems is summarized. A preliminary feasibility report is presented on the KAPL Intermediate Power Breeder Reactor cooling systems. Topics discussed include: the reactor coolant systems problems; reasons why Na and NaK were chosen as coolants; heat removal system operation at various reactor operating power levels; analyses of the proposed fuel rods during reactor operation, unloading and assumed fouled conditions, as well as reflector and breeding blanket temperature distribution and coolant requirements; test results of the full scale, 60°, top of the reactor water flow model; a description of the standby coolant system for the West Milton reactor, and the 60°, full scale, liquid metal, mockup for Sacandaga; the development of the gas cooling system for the concrete shielding; the graphite test hole area; the design of a Na pipe and reactor container heating and leak detection system; and an analysis of the primary heat removal system for the West Milton reactor at the design reactor output coolant temperature of 750°F, and reduced reactor temperatures.

- 5.400 See Also: 2.300, 3.120, 4.311, and 4.411.
- 

5.500 HANDLING PROCEDURES FOR SAFETY AND PURITY REQUIREMENTS

- 5.500 "The Liquid Metal Jet System," by E. F. Inall (Austral. Nat'l. Univ., Canberra) Atomic Energy 5: No. 3 p.6-8, July 62.

The handling and decontamination of NaK used as liquid metal slip rings (brushes) in Canberra homopolar pulse generator is described. The alloy is sprayed through jets onto faces of generator rotors. The conditions of use of the alloy (R.T. velocities about 20 m/sec., peak current densities over 40 Kamp/cm<sup>2</sup>, etc.) are outlined.

NSA 16:29128

- 5.500 CONSTRUCTION AND OPERATION OF A SODIUM CIRCULATION (SYSTEM)  
Lutz, Otto and Rex. Dietrich  
(Technische Hochschule, Braunschweig, Ger.)  
VDI Zeitschrift, 104:581-7 (1962) (In German)

A test plant was built which made it possible to circulate liquid sodium in a closed circuit and to study the behavior of conduction elements which occur in sodium-cooled reactors. The development of the sodium circulation system required special consideration and constructive solutions regarding heat transfer, the sealing of the plant, an oxide-free circulation, fire prevention, electric control, charging with sodium, and startup of the plant. Sodium fire fighting methods are described. (auth)

- 5.500 Fire Extinguishing Composition, by S. Vornovich, USP  
3,046,220.

Metal fires, such as those caused by burning of Mg, Al, Li, Na, K, Th, Ar, Hf, U are extinguished by a mixture of ground pitch, ground inert, inorganic non-fusible material, and ground NH<sub>4</sub>Cl., e.g., 1 part by weight of mineral rubber pitch was ground to 20 mesh and mixed with 4 parts clay was ground to 10 mesh. A solvent, toluene, in the amount of 5% by weight of the dry materials, was mixed with the clay. Then the pitch and 0.5 parts NH<sub>4</sub>Cl were added and mixed until the material agglomerated into particles > 100 mesh. This composition can be thrown mechanically or manually over metal fires even from a distance.

CA 57:10980c

5.500 LIQUID METAL FIRE CONTROL  
June 15, 1961.  
T. P. McGrath and E. E. Van Brunt, Jr. (CANEL)  
July 1, 1961. Contract AT(11-1)-229. 84p.

The feasibility of a drain and pump system as a method for controlling burning liquid metal without the use of an extinguishing agent was demonstrated in tests performed with lithium and NaK. (More on abstract)

NSA 15:29545

5.500 LIQUID METALS SAFETY MANUAL FOR MERCURY AND SODIUM-POTASSIUM (NaK)  
Report 0390-SD-3  
G. J. Baentel, et al., Aerojet-General Corporation, Azusa, Calif.  
Jan 1961.

The procedural requirements for use and handling of Hg and NaK in the development of the SNAP-8 program.

5.500 ALKALI METALS AREA SAFETY GUIDE (SUPPLEMENT ISSUE)  
(Y-811 (Suppl.))  
Preston L. Hill (Union Carbide Nuclear Co. Y-12 Plant,  
Oak Ridge, Tenn ) May 15, 1961. Contract W-7405-eng-26. 36p.

The Safety Guide was prepared to serve as a reference of basic principles and practices deemed necessary to carry out operations with alkali metals with the least hazard to personnel and equipment.

NSA 15:23770

5.500 "Fire Extinguishing Agents for Li, Na, and K." M.  
Friedrich, Metallurgy 15,1373-80 (1961) -

Liquids such as dibenzyltoluol and sunflower oil, and powders such as KF and graphite are the most effective against fires of  $\leq 100\text{g}$  of Li, Na, and K. The powder can be applied to the burning metal either by hand from a shovel or scoop, or from an extinguisher using Ar at low pressures ( $\leq 5$  atm) as propellant. Higher pressures are not suitable as the burning liquid metal may be spattered around. Liquid extinguishings are best applied from a graduated glass vessel, provided with a stop cock and are best for covering alkali metal fires in a vessel, but the dry powder extinguishings are more successful for free-lying, burning alkali metals spread on a floor. In attacking sure fires, gas masks, protective clothing, and gloves should be worn. The fumes have strong corrosive action. The burning metal can be scattered about by extinguishing and production of fumes can be increased by extinguishing itself. Under no circumstance must  $\text{H}_2\text{O}$ , foam extinguishing, hydrogenated hydrocarbons, or dry powders containing Na,  $\text{HCO}_3$  be used against alkali metal fires. Results obtained with a number of liquid and powder extinguishing against fires of 1, 10 and 100g of alkali metal are tabulated.

CA 56:11330b

5.500 HW-74194, The Use of Cellosolve in NaK Disposal, C. G.  
McCormick

A cellosolve-kerosene system and the protection of  $\text{N}_2(1)$  as a fire extinguisher reduced the opening of irradiated NaK containing capsules to a virtually routine task.

NSA 16:27160

5.500 TRG Report 25 Guidance in the Safe Handling of Alkali Metals. A. Thorley, and A. C. Raine. UKAEA, Reactor Group, Culcheth, Lanc. Engl., May 4, 1961

A brief summary of chemical reactions of Na with gases and some common reagents is given. Tensure max. safety, and confidence in dealing with liquid metals, advice is given on such topics as handling, cleaning of apparatus and sodium disposal. For the information of emergency teams, sections on hazards protective clothing, fire prevention, fire fighting, and first aid are also included.

NSA 16:4404

- 5.500 NPF MECHANICAL CELL NaK DISPOSAL AND FUME ABATEMENT  
G. Rey (G. E. Hanford) Sept 6, 1960 (HW-66562)

Studies demonstrated that NaK reservoirs can be safely deactivated by hack sawing under a submerged hood in a shallow water bath. (More on abstract)

NSA 15:11052

- 5.500 Reactor Development Program Progress Report for August, 1960  
Argonne National Lab.  
ANL-6215, 16 September 1960, 59 p.  
Contract W-31-109-eng-38

General research and development on water- and sodium-cooled reactors are reported along with specific development on EBWR-BORAX-V, EBR-I and EBR-II. Thermal and fast reactor safety studies are summarized in terms of fuel-coolant chemical reactions, kinetics of oxidation, ignition of reaction metals, and TREAT development. Developments in reactor fuels and materials, reactor components, separations, and advanced reactors are discussed in some detail.

NSA 15:2256

- 5.500 REMOVAL OF MOLTEN Na FROM REACTOR COOLANT SYSTEMS,  
L. Silverman and R. A. Sallach., Ind. Eng. Chem. 52 231-2 (1960).  
HB-40 (Monsanto Chemical Co.)

A mixture of partially hydrogenated terphenyls is inert, has a greater density than that of Na(l) at temperatures between 120-140°, and tends to de-wet Na in contact with SS. It is used under a precautionary blanket of N to displace Na from inaccessible spots. Tenacious or emulsified Na can be destroyed safely by adding BuOH which dissolves Na butylate and is not excessively corrosive. Na coated with carbonate will require steam and dil. acids for removal. No inflammable or explosive materials are formed and the HB-40 is reuseable.

CA 56:3090g

- 5.500 A SYSTEM OF CONVEYING LIQUIDS OR MIXTURES OF LIQUIDS  
Jiri Drasky. British Patent 848,572, Sept. 21, 1960.

A system for conveying liquid metals and radioactive liquids without the disadvantages of mechanical and electromagnetic pumps is described in which the vapors of the liquid are used to drive an injector-type pump in the circuit. Three configurations of the system are described for a liquid-metal-cooled reactor using a mixture of two metals with different boiling points (miscible and immiscible) and for pumping radioactive liquids from one container to another.

NSA 15:7469

- 5.500 TID 3544  
SODIUM-AIR ACCIDENT STUDY FOR A SODIUM COOLED REACTOR. Technical Memorandum No. 20. Edward Garelis. Apr. 6, 1959. 22p. (AECU-4161)  
\$4.80(ph), \$2.70(mf) OTS.

NSA 13:14924

- 5.500 SODIUM-WATER REACTION RATE STUDIES. L. Corrsin, H. Steinmetz, and B. Marano. May 15, 1959. 32p. (NDA-84-19) \$6.30(ph), \$3.00(mf) OTS.

NSA 13:13225

- 5.500 TID-3544  
SODIUM-POTASSIUM ALLOY. AN EXPERIMENTAL STUDY OF ITS HAZARDS.  
Asher J. Finkel and Willard B. Lyons. Arch. Ind. Health 17, 624-33 (1958) June.

- 5.500 FORCED CONVECTION LIQUID METAL IN-PILE LOOP HAZARDS EVALUATION  
PART 1 (TID-12271)  
D. Vasallo (Pratt and Whitney Aircraft Div., United Aircraft Corp.  
CANEL) June 4, 1959. Decl. Sept. 18, 1959. 21p. (TIM-602)

An evaluation and discussion of some specific potential hazards associated with the operation of the Pratt and Whitney forced-convection liquid-metal in-pile loop (designated PW-19) in the ETR are given. The effects of liquid-metal leakage to the air coolant and the reactor process water are discussed. In addition, the effects of a reactor power excursion are pointed out. (L.T.W.)

NSA 15:13481

- 5.500 AERE-Med/R-2350  
THE CONTROL OF MERCURY METAL IN THE LABORATORY  
Brooks, R. O. R. and A. Holmes  
UKAEA, Research Group. AERE, Harwell, Berks, Eng. July 1957 21p.

Mercury toxicity studies and the deduced safe working level are reported. Precautions for laboratory handling and decontamination are suggested, and monitoring procedures are discussed.

NSA 12:5199

- 5.500 Work With Alkali Metals  
Pugachevich, P. P.  
Translated by H. J. deBruin from Zhur. Fiz. Khim. v. 31,  
2140-2(1957), 6p.  
AAEC/E-27

Methods are described for purifying alkali metals in a vacuum and production techniques for alkali metal amalgams. The glass devices used for these purposes have no vacuum taps, ground in stoppers or rubber tubes; thus the purity of the metals and amalgams is not affected by the vapor of the vacuum lubricant, water or otherwise. The alkali metal amalgams produced remained unaltered in quality through years of storage.

NSA 13:20199

- 5.500 NDA-84-2  
SDR PROJECT QUARTERLY TECHNICAL PROGRESS REPORT FOR THE PERIOD MAY 1, 1957 THROUGH JULY 31, 1957. Sept. 30, 1957. 54p.

Engineering studies were made and experimental work was carried out with the objective of demonstrating the feasibility of separation of Na and D<sub>2</sub>O in the SDR reactor. For the engineering studies, a through-tube reactor design was selected. Layouts of fuel-coolant tube and header arrangements were made with a view toward minimizing the probability of mechanical failures of these Na system components. Preliminary studies on Na and D<sub>2</sub>O system requirements and on the design of the D<sub>2</sub>O moderator tank or calandria were started. A survey was made of possible barrier materials, i.e., materials which may be located between the fuel-coolant tubes and the calandria tubes to minimize the consequences of single or multiple-tube failures. Mechanical arrangements for mounting and supporting barrier materials and for detecting leaks were investigated. Conceptual designs of equipment for testing the mechanical integrity of fuel-coolant tube and header joints were completed. Major components of a single-failure rig, in which barrier materials can be subjected to Na streams that simulate Na system failures, were designed, constructed, and assembled. Preliminary design of a multiple-failure test apparatus, in which the effects of both Na and D<sub>2</sub>O failures will be investigated, has been completed. Preliminary design of a mockup test apparatus has been finished; this apparatus, which will be a full scale representation of a section of the reactor, will be used to demonstrate the reliability of integrated Na and H<sub>2</sub>O circulating systems under simulated normal and aggravated reactor operating conditions. The shielding problems associated with radiation limitations on access to header rooms for repairs and maintenance were evaluated. Temperatures, pressures, and flow rates for the secondary Na and steam systems were established.

- 5.500 LA-2147  
Stout, E. L.  
Los Alamos Scientific Laboratory, Los Alamos, New Mexico  
Safety Considerations for Handling Plutonium, Uranium, Thorium, the Alkali Metals, Zirconium, Titanium, Magnesium and Calcium. Sept. 1957. 24p. Contract W-7405-eng-36.  
US Gov. Res. Reports 30, No. 4  
p 301

- 5.500 TID-3067  
MERCURY TOXICITY  
A Bibliography of Published Literature  
Voress, H. E. and N. K. Smelcer, comps. July 1957. 54p. TISE, AEC

This title list contains 1676 references to articles on mercury toxicity that have appeared in technical journals from 1903 to the spring of 1955. The references are arranged alphabetically by senior author.  
NSA 11:12656

- 5.500 Containers for Liquid Sodium by E. R. Cornell (to E. I. DuPont de Nemours & Co.) U. S. 2,809,749, Oct. 15, 1957.

To prevent freezing of Na to the surface of cast iron or steel containers. They are phosphated. All containers are anodized in an aqueous solution of  $H_2SO_4$ ,  $H_2CrO_4$ ,  $H_3BO_3$ , or oxalic acid.

CA 52:230f

- 5.500 TID-3544  
LIQUID METAL FUEL REACTOR EXPERIMENT; PRELIMINARY HAZARDS EVALUATION FOR THE USE OF SODIUM IN THE BNL FOUR-INCH LOOP. Oct. 1957. 10p.  
(BAW-1030) \$3.30(ph), \$2.40(mf) OTS  
NSA 13:9358

- 5.500 ANL - 5719  
EXPERIMENTAL BREEDER REACTOR II (EBR-II); HAZARD SUMMARY REPORT.  
L. J. Koch, H. O. Monson, D. Okrent, M. Levenson, W. R. Simmons, J. R. Humphreys, J. Haugsnes, V. C. Jankus, and W. B. Loewenstein.  
May 1957. 401p.

The EBR-II consists of an enriched core surrounded by a fertile blanket of depleted U. The fuel pins fit loosely in a thin walled tube filled with static Na for a heat transfer bond. Heat is removed by the primary Na flowing along the outside of the fuel tube. The fuel element lends itself to remote control fabrication methods. Effort was made to achieve a rigid, close-packed arrangement of the fuel and to produce preferential bowing such as to effect a probable bowing coefficient which is essentially zero or negative. Reactor control is effected by movement of fuel into and out of the reactor core. Heat is removed by the primary Na coolant system and transferred to the secondary Na system in a shell-and-tube heat exchanger. The reactor and entire primary system, including heat exchanger, are contained in a large vessel (primary tank) and operate completely submerged in coolant. The large volume of Na in the primary system provides a reliable source of constant temperature coolant. Shutdown cooling is accomplished by natural convection. This bulk volume of Na is also used as coolant during reactor unloading. The reactor, primary coolant system, and all associated equipment are contained in a building in the form of a gastight cylindrical steel sheet (with a normal safety factor of approximately four). Two potential sources of accidental energy release are treated separately.

- 5.500 Sodium Vapor Detection Test, Whitlock, D. L. North American Aviation, Inc., Downey, Calif. NAA-SR-Memo 1552 January 9, 1956, 8p.

The Westervelt method of sodium vapor detection (passing an inert gas into the area presumed to contain sodium vapor and bubbling the gas through water containing thymol blue indicator) was evaluated for use in detecting leaks in the SRE control rods. The method was found unsatisfactory for the proposed use.

NSA 14:18853



5.500 SODIUM-STEAM REACTION EXPERIMENTS. W. B. Woolen, D. Scott, and F. R. Dell. Oct. 1956. 19p. (AERE-CE/R-2158)

In view of the apparent complexity of the reaction between Na and steam, a large-scale experiment was devised as a climax to a number of early bench experiments, in order to simulate as closely as possible the effect of a small steam leak into Na in a Na/superheated steam heat exchanger. The reaction resulting from passing superheated steam through a 3/32-in.-diam hole into 44.8 lb of Na at temperatures of 450°C down to 282°C in the presence of Ar proceeded smoothly and inaudibly without any marked change of either temperature or pressure. Hydrogen was present in the gas and was given off as soon as the reaction commenced, but no O<sub>2</sub> or steam was detected. In a subsequent test dry Ar was passed through the same Na, and the presence of appreciable amounts of H<sub>2</sub> in the outgoing Ar indicated that NaH was present in the reaction products. Subsequent analysis of the contents of the reaction vessel at room temperature indicated that they were Na, NaOH, and NaH with less than 0.1% peroxide. There was no corrosion, by visual observation, of the 18/8/1 stainless steel nozzle or equipment.

5.500 NP-7418  
REMOVAL OF MERCURY IN RESIDUAL SODIUM FROM A DRAINED SYSTEM USING A SODIUM FLUSH  
Batutis, E. F., et al.  
MSA, Callery, Pa.  
17 Jan 1956, 9p. Contract NObs-65425  
Memo Report 103

The use of a fresh sodium charge to dilute mercury in the residual sodium of a drained system is a practical method for eventually removing the mercury. This was confirmed by using a hold-up pocket filled with a sodium amalgam and circulating fresh sodium past the 1/2 in. pocket opening. The sodium amalgam in the bottom of the pocket was more effectively diluted by raising the system temperature to 600 F. The major portion of the mercury in the pocket, mixed with the flush sodium circulating at 2.5 fps. at any temperature from 350 to 600 F in 15 to 30 min.

NSA 13:12439

5.500 SAFE HANDLING OF ALKALI METALS  
Marshall Sittig  
(Ethyl Corp., New York).  
Ind. Eng. Chem. 48 227-9(1956) Feb.

Provision for specific storage facilities and safe handling of alkali metals are discussed. (auth)

NSA-10-4687

5.500 DYNAMIC EFFECTS OF NaK-WATER REACTIONS IN THE GENIE SYSTEM.  
O. R. Schurig. Mar. 19, 1951. Changed from OFFICIAL USE ONLY  
Oct. 3, 1956. 32p. (R51GL49)

5.500 KAPL-557  
Knolls Atomic Power Lab., Schenectady, N. Y.  
Summary Report of Reaction Tests of Various Materials Tested with Sodium and Sodium-Potassium Nelson, C.O.  
June 1, '51. Changed from Official Use Only June 26, 1956. 51 p.  
Contract W-31-109-Eng-52

Tabular data show the methods, conditions, and observations of tests carried out in air to determine the reactions of liquid Na and NaK with Al roofing, cloth (including protective clothing), laboratory equipment, fire-extinguishing materials, insulating and packing materials, oils paints, brass and Cu screens, and Li fire-extinguishing materials.

NSA 11:2251

5.500 Biram, J. G. S.  
Some Aspects of Handling Mercury  
Vacuum 5, 77-91 (1955).

47 references.

Metals Review 31, 440A.

5.500 UN-866  
LIQUID METAL HANDLING. S. G. Bauer. July 12, 1955. 14p.

Hazard, specific problems, and equipment for the handling of liquid metals are discussed.

5.500 NP-5990  
THIRD FLUID TUBE SHEET HAZARD TEST. Memo Report 101. W. Milich,  
E. A. Schultz, E. C. King, and R. E. Lee. Dec. 28, 1955. 9p.  
Contract NObs-65426.

Three tests were made, simulating as closely as possible a third fluid NaK to water break at the tube sheet, to determine the extent of the hazard in the event of a tube failure between water and the third fluid NaK in an evaporator similar to the one in Sig. The tests were run in a horizontal and 30° pitch either way, forcing the 200° F water into the 700° F NaK under a 200 psig driving pressure. There was no immediate hazard or reaction of explosive violence during the runs. At the time of rupturing the disc between the NaK and water, the pressures on both sides equalized almost instantly and continued to hold for some time.

5.500 AECU-3200  
Massachusetts Inst. of Tech., Oak Ridge, Tenn.  
Engineering Practice School  
Vapor Traps for Handling Liquid Sodium  
Erickson, A. J. et al  
August 25, 1951, 11p. For Carbide and Carbon Chemical Div. (K-25 Plant).  
Contract W-7405-Eng-26. Subcontract 70 (KT-109)

Proposals for removing Na aerosol by an electrostatic precipitator, a copper coil condenser, and a bubbler were tested and evaluated. All were at least partially effective, the condenser proving to be the most practical to operate.

NSA 11:3885

5.500 AECU-1273  
Knolls Atomic Power Lab.  
GUIDE TO LIQUID METAL HANDLING. Liquid Metals  
Safety Committee, D. B. Nelson, Chairman. Mar. 1, 1951.

The three principal hazards which may be encountered in the use of liquid metals (Na, NaK, etc.) are explosions and fire resulting from their contact with water or other materials of a similar nature, fire resulting from their exposure to air, and injury to personnel by liquid metal contacting the skin. The present guide describes personal safety gear for protection of eyes, hands, etc.; first aid for liquid-metal burns; precautions to be taken in disassembling or repairing liquid-metal systems; tags and signs to be placed in area or on containers and equipment; tools, shields, etc., to be placed on an emergency panel; and fire-fighting techniques.

NSA 5:3424

5.500 THEORETICAL ESTIMATE OF MAXIMUM POSSIBLE NUCLEAR EXPLOSION.  
H. A. Bethe. Jan. 31, 1950. Dec. Feb. 22, 1957. 31p. KAPL-294

The maximum nuclear accident which could occur in a Na-cooled, Be moderated, Pu and power producing reactor is estimated theoretically.

5.500 KAPL-337  
Knolls Atomic Power Lab., Schenectady, N. Y.  
INVESTIGATION OF ALPLAUS ATMOSPHERIC PRESSURE SODIUM STILL.  
E. E. Baldwin. July 6, 1950. Decl. Nov. 22, 1955. 30p.  
Contract W-31-109-Eng-52.

As a result of two fires in the sodium still, an extensive investigation was made to determine the type and extent of damage and their cause. Results indicate that the external erosion and pitting was caused by action of the products of combustion of the Na fires, the argon line plug was due to localized oxygen contamination of the Na, and the internal surface damages were negligible.

NSA 10-3198

5.500 KAPL-267  
PROGRESS REPORT NO. 39; SECTION IV-REACTOR ENGINEERING; OCTOBER 1-31, 1949. Nov. 23, 1949. Decl. Mar. 30, 1957. 31p.

To explore the feasibility of extinguishing sodium fires by flooding with inert gas, a fairly large scale test was made. Molten Na, 6 inches deep in an 18-inch diameter 24-inch deep, open-top container, was ignited. Jets of Ar were directed into the container. Unreasonably large amounts (approximately 50 cfm) were necessary to extinguish the blaze. It was concluded that this method cannot be relied upon for the reactor liquid-metal heat-transfer system. The stand-by cooling system mockup has been run with power input of 57 kw corresponding to 3 percent heat removal from the full reactor operating at 18 mw. Highest temperature measured in the reactor core part of the mockup was 560°F for that power. This temperature is somewhat lower than the value calculated for the same set of conditions, giving encouragement that the stand-by-cooling system as proposed may do the job.

5.500 KAPL - M - JEZ - 1  
RECENT DEVELOPMENTS ON THE STANDBY COOLANT SYSTEM FOR THE WEST MILTON REACTOR. John E. Zerbe. June 20, 1949. Decl. Mar. 27, 1957. 12p.

The work done previously on the Standby Coolant System was reviewed in the light of more recent reactor designs and heat transfer data. It has been found that if a NaK-Na heat exchanger consisting of 16-1½" OD 60 mil wall stainless steel tubes is used, the thermal stress is reduced to approximately 22,000 psi when 2½% of 30 Mw is transferred under steady state conditions. Further calculations based on dissipating 2½% of 30 Mw have shown that the thermal stress is not influenced noticeably by the temperature rise in the NaK system. This is for both 80-20 (eutectic) NaK and 50-50 NaK. However, assuming the NaK-air exchanger is placed at a height of 55 feet the factor of safety for the various temperature rises in the NaK loops is different. Thus, for 80-20 NaK, if  $\Delta T_{NaK}$  equals 200°F, calculations show that the exchanger must be at least 40 feet in the stack; for  $\Delta T_{NaK} = 150^\circ$  the exchanger must be located at about 86 feet. If 50-50 NaK were used, the factor of safety would be greater than with 80-20 NaK.

5.500 METHODS OF HANDLING, STORING, SHIPPING, AND TRANSFERRING LIQUID SODIUM - POTASSIUM ALLOYS (MSA)  
Preliminary Report 3, June 28, 1947. (Appendix to Report NRL-C-3105, April 1947)

5.500 See Also: 3.140.

---

5.600 AEC-tr-5412

THE NATURE OF  $O_2$  IN LIQUID Na, B. A. Nevzorov, IAEA Preprint  
CN 13/40 14 p. (In Russian) To be published (IAEA Conf. at  
Salzberg on Corr. of Reactor Materials

Experiments were conducted to investigate the nature of  $O_2$  dissolved in Na(liq) at temps of 300-600°C. A series of experiments consisting of passing a direct current thru liquid Na revealed transport of  $O_2$  to the anode and a relatively constancy in the amount of  $O_2$  transported per amp hr of current passed. It was found that at 300°C the amount  $O_2$  transported is approximately 0.07 mg/am-hr. and that at 600°C this amount increases to 0.474 mg. Calculations are made indicating that transport occurs thru polarization of negative  $O_2$  ions present in the Na by the direct current field. Some remarks are made on the mechanism of dissociation of NaO molecules in the Na at high temperatures, and on the mechanism of corr. of struct. materials and of carbon transport in liquid Na due to presence of negative  $O_2$  ions

NSA 16:32956

5.600 NAA SR5363 CORROSION AND RADIOACTIVE ACTIVITY TRANSFER IN THE SRE  
PRIMARY SODIUM SYSTEM, Oct. 30, 1961.

An evaluation extending over 2 years was made of primary system Na and of stainless steel, and Zr and Be specimens exposed in hot and cold legs of a bypass loop in primary system of Sodium Reactor Experiment (SRE). The metal specimens were checked for physical property changes and for radioactivity transfer of hot to cold leg surface. Stainless steel tabs underwent no significant micro-structural changes. However, the Zr specimen showed varying degrees of hydriding, generally characterized as moderate. Severe hydriding of one Zr tab resulted in serious embrittlement. Low  $O_2$  pickup on Zr specimen verified hot-trap  $O_2$  control of SRE primary system Na to less than 10 ppm, with a correspondingly low amount of oxidation of Zr moderator cans.

NSA 16:1191

5.600 NAA-SR-6162, Nitriding of Type 304 Stainless Steel in a Sodium-Nitrogen System, Gill, J. T., Bokros, J. C., (May 30, 1961).

Type 304 stainless steel is nitrided in 1000°F sodium system covered with nitrogen gas. Observations were made using a flowing-sodium loop. The degree of nitriding is heaviest at the interface between the sodium and nitrogen. The nitriding process strengthens the type 304 stainless steel at elevated temperatures and produces a marked decrease in its ductility. The stress-rupture life is greatly decreased at 1000°F because of nitriding. At a deflection of 0.76 in. producing a stress of 36,000 psi, the flexural fatigue life is significantly increased by nitriding.

5.600 QUALITATIVE TEST OF THE INERTNESS OF GAS TO COVER SODIUM -  
POTASSIUM ALLOYS

E. K. Inall (Australian National Univ. Canberra)  
Rev. Sci., Instru., 32:1257-8 (Nov 1961)

A sampling device, which consists of a glass envelope enclosing a glass bowl, was designed for cleaning NaK surfaces. The surface in the bowl can be cleaned by passing a 20 amp current between two electrodes, so that NaK is pumped up through the tube into the bowl. This produces a clean surface on the NaK in the bowl, if the gas is free of reactive contaminants, or if the gas has been pumped out, leaving a pressure of less than 1 mm Hg, so that the remaining contamination is rapidly removed by reaction with the NaK.

NSA 16:13345

- 5.600 EXAMINATIONS OF PUMP IMPELLERS FROM SODIUM AND FUSED SALT PUMP  
ENDURANCE TESTS  
J. H. DeVan (ORNL) April 10, 1961, 13p (CF-61-4-77)

Examination of an Inconel impeller used in Na up to 1250°F showed heavy carburization along exposed surfaces. The cause of carburization may be associated with the type of gas purge utilized for these pumps.

NSA 15:18436

- 5.600 COOLING BY LIQUID METALS. PROBLEMS OF COMPATIBILITY  
R. Darras (Commissariat a l'Energie Atomique, (Paris)).  
Energie Nucleaire (France), 3:128-38 (Mar- Apr 1961)  
(In French)

The properties of liquid metals as coolants are reviewed; corrosion and structural problems encountered in the use of these liquid metals are discussed. Purification and oxygen content control are considered, especially in the case of Na and NaK.

NSA 15:19904

- 5.600 NUCLEAR FUELS AND MATERIALS DEVELOPMENT  
(Div. of Reac. Development AEC) Feb. 1961, 172 p. (TID-11295)

Included in this summary is the corrosion of cladding materials in liquid metal and the effect of O<sub>2</sub>, N<sub>2</sub>, and H<sub>2</sub> on the mechanical properties of Cb was investigated.

NSA 15:12475

- 5.600 NAA-SR-7325  
SODIUM CONDENSING HEAT TRANSFER. AN EXPERIMENTAL STUDY OF ONE  
ASPECT OF SODIUM COOLED REACTOR SAFETY.  
Reed, G. L., and Noyes, R. C.  
(Atoms International, Div. of North American Aviation Inc.,  
Canoga Park, Calif.) Dec. 15, 1961. Contract AT(11-1)-Gen-8. 55p.

A problem of emergency heat removal in Na-cooled reactors is concerned with the condensing of Na vapors that might be generated as a result of a hypothetical loss-of-heat-sink accident. An evaluation, in which the Na vapor condensing in the restricted region below the loading face shield of the Hallam Nuclear Power Facility was made, to determine heat removal capability. Experimental determinations of condensing heat transfer rates in a model of this region were made. The primary resistance to heat transfer was found to be noncondensable gases present in the system. The gas (usually He) would be present because of its normal use as a cover gas in the core tank. A theoretical equation based on gaseous diffusion was derived, and the heat transfer rate is predictable provided the quantity of noncondensable gas is known. Further experiments were used to study the venting behavior of the gas space below the HNPF loading face shield during simulated accident conditions. These experiments provide information required to predict the quantity of noncondensable gas left in the system after a postulated accident and to predict associated heat transfer rates. Two venting methods were studied to determine the most efficient emergency venting procedure. It was found that if the region immediately below the top shield is vented, sufficient heat removal capability exists to condense all Na vapor that could be generated by afterglow heat. This would assure safety of the system by eliminating the possibility of any pressure buildup as a result of the postulated accident. (auth)

- 5.600 PROCESS FOR REMOVING THE HEAT DEVELOPED INSIDE A NUCLEAR REACTOR WITH PRE-PRESSURIZED MERCURY VAPOR AS COOLANT  
K. Diebner. French Patent 1,225,614. July 7, 1960

During the startup of a reactor, liquid Hg is pressurized inside the cooling system by an inert gas; this gas circulates through the reactor and has a sufficient pressure to remove the heat developed. As the coolant temperature increases, the vapor pressure of the Hg increases and the proportion of Hg vapor in the cooling increases. Finally the vapor pressure of the Hg exceeds the pressure of the gas used to pressurize the Hg before the start-up, so that the heat removal in the reactor is almost entirely due to the mercury vapor. When the reactor is at full power, the Hg in the system has a temperature sufficient for it to remain in the vapor state in all parts of the system. (NPO)

NSA 15:33035

- 5.600 THE LARGE COMPONENT TEST LOOP  
H. Stohl  
USAEC Report NAA-SR-4386, (AI) Mar. 1, 1960

2½ wt % chromium - 1 wt % molybdenum alloy steel pipe in nitrogen - blanketed Na at 1200 gal/min flow rates with temperatures up to 1000°F.

- 5.600 QUARTERLY STATUS REPORT ON LAMPRE PROGRAM FOR PERIOD ENDING NOVEMBER 20, 1960  
(LASL) Dec 1960, 29p. Contract W-7405-eng-26. (LAMS-2487)

Abstract refers to thermocouple failure, the cover gas system, and tantalum corrosion in sodium.

NSA 15:8345

- 5.600 NAA-SR-3829  
AN ADVANCED SODIUM-GRAPHITE REACTOR NUCLEAR POWER PLANT  
(AI) J. R. Churchill and J. Renard. March 15, 1960 162 p.  
Contract AT-11-1-GEN-8. OTS

An advanced Na-cooled, graphite moderated nuclear power plant is described which utilizes high-pressure, high-temperature steam to generate electricity at a high thermal efficiency. Questions remain regarding the use of N<sub>2</sub> as a cover gas over Na at 1200°F.

NSA 14:15456

- 5.600 AECU-3656.  
G. C. Wheeler, Knolls Atomic Power Lab., Schenectady, N. Y.  
The Effect of Nitrogen-Covered-Sodium on S2G Structural Materials  
March 21, 1957. 23 pages. Contract W-31-109-Eng-52.

Tests were made to determine the effects on structural materials of using nitrogen as a cover gas for the liquid sodium in the S2G system. Various materials including beryllium, 18-4-1 tool steel, and 347 stainless steel were exposed to N<sub>2</sub>-covered Na, both flowing and static, at temperatures of 600 to 1100°F. The effects of several variables, including temperature, irradiation and sodium flow rate, were investigated. The effects on the specimens were monitored by weight and dimensional changes, metallographic and X-ray examinations, and mechanical tests. Many of the materials, including beryllium, tool steel and stainless steel were found to nitride. The nitrides of stainless steel and tool steel form an adherent "case" on the metal surface, but are more readily corroded than their parent metals. Thus, in flowing Na no case is formed except on protected portions of the metal surface, while in static Na a case is formed which increases in thickness with increasing time. In flowing Na the mutually competing reactions of case formation and corrosion, plus solubility of N<sub>2</sub> in the metals, make the weight changes unreliable as indices of metal loss, even for beryllium, whose nitride is inadherent. Consequently, directly-measured metal losses must be used to follow the reaction rates in flowing sodium. The effects of sodium-produced nitride cases on mechanical properties of . . .

- 5.600 NP-6178  
Mine Safety Appliances Co., Callery, Pa.  
A Study of Nitrogen as a Cover Gas in Sodium Systems  
Technical Report 53 by Batutis, E. F. et al.  
Dec. 7, 1956. 25p. Contract NObs-65426

Nitrogen used as a cover gas in several MSA Na systems, ranging from 900 to 1100°F and 1 to 7 fps, did not induce excessive corrosion of Types 304 and 347 stainless steel and tool steel specimens. Average corrosion rates found of the stainless steels ranged from +0.01 to +0.23 mg/cm<sup>2</sup>-mo and tool steel ranged from -0.24 to -0.96 mg/cm<sup>2</sup>-mo. The corrosion rate of Be in a 1100°F Na system (S2G mock-up) for six specimens exposed for 90 days averaged 1.27 mg/cm<sup>2</sup>-mo. This rate of Be attack may be undesirable in some applications and would require definite consideration in design work. Factors affecting Be attack to varied degrees were: entrained N, Ca content, temperature and distance to Na-N interface. The order of magnitude of these factors was not definite but the last mentioned seemed to be least effective. These factors were negligible in the corrosion of stainless steels and tool steel in the MSA test systems.

NSA 11:3398

- 5.600 Nitrogen Containing Two Percent Oxygen as a Sodium System Cover Gas. Technical Report No. 49. E. F. Batutis, J. W. Mausteller, and C. A. Palladino. Apr. 10, 1956. 22p. Contract NObs-65426. (NP-5935).

Impure nitrogen (98 vol % N<sub>2</sub>-2 vol % O<sub>2</sub>) has been used as a sodium system cover gas in a mockup S2G expansion tank and in normal loop operation. A 1 in. line in the gas phase of the mockup S2G expansion tank plugged completely with oxide after 336 hr at 1000 F, 180 hr at 350 F (drained) and 277 cu ft of gas passed through the system. Nitriding is general throughout the entire loop, especially at the interface. Operation of a 1 in. pumped sodium loop using impure nitrogen cover gas also resulted in plugged gas lines, as well as plugged drain lines, however, a better cold trap would have prevented the latter. Nitrogen containing 2 vol % O<sub>2</sub> is not recommended as a cover gas for sodium systems. Pure nitrogen would be satisfactory pending investigation of nitriding at higher temperatures.

- 5.600 Impure Cover Gas Effects: Expansion Tank. Memo Report 96. E. F. Batutis, C. A. Palladino, and J. W. Mausteller. Nov. 17, 1955. 11p. (NP-7414) NSA 13:11854. TID 3544

- 5.600 Progress Report No. 31 for October and November 1955. W. J. Posey, ed. Dec. 12, 1955. 72p. Contract NObs-65426. NP-5840

Testing of the 3-Mw steam generators was continued. Level indicators for liquid Na, combined valve connect and disconnect, and AC induction pumps for liquid metals are described. Microfissure propagation has been observed as a result of quenching heated weld specimens with liquid Na. The feasibility of using impure N<sub>2</sub> as a cover gas for sodium systems was demonstrated. Investigations were continued on the corrosion of Zr by liquid Na, the removal of Hg from sodium systems by amalgamation with Cu, and the radiation hazards arising from leaks in liquid metal systems.

- 5.600 KAPL-M-EGC-21  
Knolls Atomic Power Lab., Schenectady, N. Y.  
Preliminary Experiments on the Nitriding of Reactor Materials in Sodium  
Brush, E. G. and C. R. Rodd. Sept. 22, 1955. 9p.  
Contract W-31-109-Eng-52

The use of  $N_2$  as a cover gas in the SIR Mark B primary coolant system poses the problem of possible nitriding to reactor structural materials. Preliminary tests have been conducted at KAPL and in the MTR in sodium under a pressurized  $N_2$  blanket. Results show that at 900 and 1100°F the ferrous alloys and Be readily nitride under these test conditions. The thermodynamics of the reaction indicate that transport of  $N_2$  in Na (diffusion, entrainment, or  $Ca_3N_2$  as a carrier) may be the rate controlling factor. Further experiments must therefore be performed to evaluate the problem under conditions more closely resembling those of actual reactor operation. NSA 10:10954

- 5.600 KAPL-M-GHE-1  
Knolls Atomic Power Lab., Schenectady, N. Y.  
Report of Literature Survey on Liquid-Gas Entrainment Problems  
Epstein, Gilbert H. July 7, 1955. 16p. Contract W-31-109-Eng-52

An exploratory study has been made of literature pertaining to the phenomena of interfacial particles in gas-liquid systems to learn what factors influence the behavior of bubbles or other types of entrainment in both static and dynamic two-phase systems. The aim is ultimately to apply these findings and their corollaries to problems associated with filling and draining Na systems, where gas entrainment appears undesirable, both from heat transfer and hydraulic considerations. NSA 10:10817

- 5.600 BNL-756  
LIQUID METAL RESEARCH AT NASA-LEWIS RESEARCH CENTER  
James P. Lewis, Lewis Research Center, Cleveland, Ohio  
Second Annual High Temperature Liquid Metal Heat  
Transfer Technology Meeting, BNL, May 17 and 18, 1952

The paper outlines the major liquid metals research and development efforts at Lewis Research Center. The work includes: a Two-Phase Sodium Loop for flashing sodium vapor; the Sodium Turbine Facility using refractory metals; Pump Test Facilities including one low pressure K pump and one high pressure Na pump; Alkali Metal Heat Transfer Facility using EM pumps and Cb-1Zr above 1500°F and type 316 stainless below; A Space Radiator and Condenser Facility using a NaK loop for boiling potassium; Bearing and Seal Studies using liquid Na environments; Mercury Programs relative to the radiator problem in zero gravity similar to SNAP VIII conditions; and several Materials Support Programs directed to advanced materials and refractory metals for all alkali metals, and Hg loop corrosion.

- 5.600 See Also: 1.410, 2.300, 2.330, 3.120, 5.200, and 5.300.





6.000

LOOP COMPONENTS



6.100 MEASUREMENT DEVICES

- 6.100 MEASUREMENT OF THE SPEED OF ULTRASOUND IN MOLTEN ALKALI METALS  
Yu. S. Trelin, I. N. Vasil'ev, and V. V. Roshchvplcin. Atomnaya  
Energ. 9: 410-11 (Nov. 1960)(In Russian)

The pulse interferometer was used in measuring the ultrasonic speed in sodium and eutectic NaK at 700°C . . . It is also shown that ultrasonics can be efficiently used for testing construction material wetting by alkali metals.

NSA 15:10947

- 6.100 NP-8457  
General Electric Co. Light Military Electronics Dept.,  
Schenectady, N. Y.  
RESEARCH ON LIQUID METALS AS POWER TRANSMISSION FLUIDS. Progress  
Report No. 3 (for) March 1, 1959 to June 1, 1959. R. C. Kumpitsch.  
June 1959. 26p. Project No. 8-(1-7331). Contract AF33(616)-5917.

The research effort, during this report period, on liquid metals as power transmission fluids was concerned with establishing a 1-gpm, 3000-psi, 1000°F, NaK-77 test flow loop. The low-pressure portion (console) of the test loop has been completely assembled. A control panel for operation of the loop was fabricated. The "console" was installed in the liquid metals test area and completely instrumented, with exception to the loop's low-pressure sensing and recording equipment. The design of the high-pressure NaK pump mounting and speed drive fixture for the inert atmosphere "glove box" was completed. This mixture is currently being constructed. Continuing progress is being made on the manufacture of the high pressure-temperature NaK staged gear pump. No improvement in the delivery schedule for this pump has been obtained. Difficulty is being experienced in the procurement of correctly fabricated carbide material for this NaK pump. Negotiations are currently underway with both the pump and material vendors to resolve the problem. The revised liquid metals program schedule is included. (auth)

NSA 14:11703

- 6.100 Pokrovskii, N. L. et al.  
Apparatus for Measuring Surface Tension and Density of Liquid  
Metals in Vacuum  
Fizika Metallov i Metallovedenie 2, No. 3, 546-551 (1956).  
Metals Review 31,  
No. 2, 61-P

- 6.100 TID-3544  
INITIAL TEST OF SODIUM PUMP AND INSTRUMENT LOOP. R. Cygan. Dec. 1,  
1954. Dec1. No. 6, 1958. 35p. (NAA-SR-Memo-1178) \$3.30(ph),  
\$2.40(mf) OTS.

NSA 13:11500

- 6.110 IMPROVEMENTS IN OR RELATING TO ELECTROMAGNETIC FLOWMETERS  
 Thorpe, Percy Eric (To United Kingdom Atomic Energy Authority)  
 British Patent 899,095, June 20, 1962.

An electromagnetic flowmeter is designed for operation under high temperature and pressure conditions. The flowmeter comprises a body member defining a bore and an electrically insulating sleeve loosely lining part of the bore. The sleeve is designed so that fluid may penetrate between the sleeve and body to balance the pressure across the sleeve. Two diametrically opposed electrodes are arranged to contact the fluid to measure the induced emf. (D.L.C.)

- 6.110 CALIBRATION AND TESTING OF 2- AND 3½ IN. MAGNETIC FLOWMETERS FOR HIGH-TEMPERATURE NaK SERVICE  
 R. G. Affel, G. H. Burger, and C. L. Pierce, Mar. 4, 1960, 26 p.,  
 Contract W-7405-eng-26. OTS.

High-temperature calibration tests were made on 12 magnetic flowmeters with NaK as the flow medium (ORNL-2793).

NSA 14:10602

- 6.110 An Investigation of Possible Flowmeter Types for the Large HNPf Piping  
 Turner, G. E.  
 Atomics International, Division of North American  
 Aviation, Inc., Canoga Park, Calif.  
 NAA-SR-Memo-3407, 11 Dec. 1958, 14p.

Various types of flowmeters were evaluated for use on large sodium piping of the Hallam Power Reactor relative to availability, cost, and relative merits. Permanent magnet flowmeters were found most applicable.

NSA 15:4762

- 6.110 Free Thermal Convection of Mercury in a Closed Circular Tube in a Transverse Magnetic Field  
 A. G. Smirnov (Soviet Physics--Tech. Physics, 1958,3,(7), 1429--  
 1434 (published 1959) See M. A., 26,361

- 6.110 AERE-X/M-169  
 Shercliff, J. A.  
 Atomic Energy Research Establishment (Gt. Brit.)  
Tests with Mercury of a Rotary Flowmeter for Liquid Metals.  
 May 1957; 8p.

Tests are described on a novel and simple type of flowmeter in which magnets mounted on wheels are dragged around by the motion of a liquid metal in an offset tube between the wheels. The optimum degree of offset was established with a non-conducting tube and the meter's characteristics studied. Owing to the size of the frictional forces in comparison with the magnetic forces when mercury was employed, the results were liable to high scatter, and when the mercury flowed in a conducting stainless steel tube, sustained steady running was impossible under the conditions available, although deceleration measurements showed the presence of the magnetic driving force.

Title Announcement Bull. U58-13

- 6.110 D-C Magnetic Flowmeter for Liquid Sodium Loops  
 G. G. Pfister and R. J. Dunham (Knolls Atomic Power Laboratory,  
 Schenectady, New York)  
 Nucleonics 15, No. 10, 122-4-(1957). October.

6.110 OPERATIONAL PERFORMANCE OF MAGNETIC FLOWMETERS ON A SODIUM COOLED REACTOR. E. R. Gasser. (1957). 17p. (AECU-3853; M-6221) \$3.30(ph), \$2.40(mf) OTS. NSA 13:1278

6.110 Electromagnetic-Type Flow Meters by Linford, A. Fluid Handling No. 87, pp. 98-9 (1957).

An apparatus is described consisting of a permanent or electromagnet arranged so that the magnetic flux between N and S poles traverses the pipe at right angles to the direction of flow. The e.m.f. generated by flowing liquid is amplified and measured in terms of rate of flow. This e.m.f. is directly proportional to the mean velocity of flow irrespective of the profile of the velocity curve across the pipe. Thus the accuracy of metering is not influenced by the viscosity of the liquid and this meter can be used to measure the flow of non-Newtonian liquids. In addition the velocity/e.m.f. relationship is linear and is not influenced by the density of the liquid and solids in suspension. In order for this apparatus to function properly the specific resistance of the liquid must be of the order of one megohm-centimeter or less. This excludes all gases, petroleum products, and certain chemicals and hydrocarbons.

CA 51:10965

6.110 Principle of Electromagnetic Flowmeters Without External Magnets Colin, Alexander J. Appl. Phys. 27, 965-6 (1956).

The author describes briefly how it would be possible to dispense completely with an external magnet on an electromagnetic flowmeter. The new approach utilizes a non-homogeneous magnetic field. The applicability of this approach is limited to the electric conductors, such as liquid metals. The magnetic force of the proposed flowmeter is generated as follows: a large alternating current, derived from a step down transformer, is passed axially through the liquid metal in a sufficiently long circular pipe section.

6.110 AERE-Inf/Bib-93 (4th ed.) Gt. Brit. Atomic Energy Research Establishment, Harwell, Berks, England Electromagnetic Pumps and Flowmeters. A Bibliography of Literature References and Readily Available Reports by Greenhill, M. and C. S. Sabel, comps, October 1956. 1 Op. 55 references

NSA 11:6345

6.110 Removal of Entrained Gas From a Sodium System Barker, K. R. and J. W. Mausteller Mine Safety Appliances Company, Callery, Penna. Technical Report No. 50 Contract NObs-65426. 14p. July 12, 1956.

An efficient method for removal of entrained gas in a Na system similar to the S2G primary coolant system is described. A study of the behavior of air-water mixtures in a glass loop showed how gas moved through the system and gave a better understanding of two-phase flow. Air could be held up at various points depending on the velocity: down-stream end of upper horizontal run at 0.25 fps, in the vertical downward leg at 0.25 to 0.50 fps, and at the bottom of the vertical downward run at 0.50 fps. Entrained gas in the Na system caused erratic flowmeter and pump performance and flow stoppage at low velocities. An expansion tank located above the loop will remove gas at any flow condition great enough to transport gas to the vent. If it is necessary to transport gas downward to the expansion tank a minimum velocity must be exceeded. This was found to be between 1.5 and 2.3 fps in a 1 in. line 6 ft long. Gas removal rate is a function of velocity in the expansion tank like, but is independent of the main loop velocity. Entrained gas can be removed if liquid velocities are kept above 2 ft/sec and a normal separator is used in a by-pass line.

- 6.110 NP-1108  
FRICTIONAL PRESSURE DROP FOR SODIUM-POTASSIUM ALLOY: TECHNICAL REPORT 1.  
Robert E. Lee. Sept. 1, 1949. Decl. Mar. 30, 1955. 21p. Contract  
N9onr-85801.

Tests were made measuring pressure drop of eutectic Na-K through a straight 1/2-in., seamless type 304 pipe. Plots are presented of the friction factor vs. Reynolds number curves as calculated independently using an orifice meter and an electromagnetic meter for flow measurements. Reasonable agreement was obtained between presently reported values calculated from the orifice meter and those previously. These curves are at variance with the values presently obtained from the electromagnetic flowmeter which give a friction factor vs. Reynolds no. curve agreeing closely with those recommended by Moody. Curves are given showing the variation of friction factor with Reynolds no. of 3,000 to 176,000. Since there appears to be more reason to validate the electromagnetic flowmeter values, good agreement is obtained with the curves recommended by Moody, so that ordinary methods of calculating pressure drop should give values sufficiently accurate for design purposes.

- 6.110 KAPL-M-SCT-5 (Rev. 1)  
Knolls Atomic Power Lab., Schenectady, N. Y.  
Calibration of 8" Magnetic Flowmeter by Use of a Calibrated Orifice  
Duffy, E. J. and J. J. Marguin May 24, 1955. 34p. Contract W-31-  
109-Eng-52.

A calibrated, sharp-edge orifice was installed and used for the calibration of the Mark I-i eight-inch magnetic flowmeter. This flowmeter is one of the two being used for performance testing of Mark B electromagnetic pumps, both prototype and production models. Repeatable data were obtained throughout the entire calibration period of eleven days. As a result, it is now possible to establish the relationship between this magnetic flowmeter output signal and sodium flow which, to date, has been in question. From the test it is now certain that the relationship between flowmeter output and flow does deviate from linearity above the higher flow rates (1900 gpm and over). Pump performance, based on flow measurements derived from magnetic flowmeters, has been affected to such an extent that, because of this deviation, it has not been possible to establish the rated voltage or accurate performance curves on the electromagnetic pumps.

NSA 10:10825

- 6.110 AERE-Inf/Bib-93(3rd Ed.)  
Gt. Brit. Atomic Energy Research Establishment, Harwell, Berks, England.  
ELECTROMAGNETIC PUMPS AND FLOWMETERS.  
A Bibliography. M. Greenhill. 1955. 5p.

Available unclassified reports from the Geneva Conference, the A.E.R.E. and the A.E.C. are listed in this bibliography. (D.E.B.)

NSA 10-2699

- 6.110 A Report on the Calibration of Two Eight-Inch Magnetic Flowmeters -  
Mark I-2 and Mark II  
Astley, Eugene R.  
General Electric Company, Nov. 10, 1954. 31p. (R54GL303).

Methods of calibration were explained for verification of the theoretical performance of 8-in. magnetic flowmeters used in other than ideal entry conditions. The flowmeter should have a calibration accuracy within  $\pm 3\%$  of the full scale of 3400 gal/min.

- 6.110 NEPA-1423; BW-5205  
EROSION AND HEAT TRANSFER WITH LIQUID METALS; PROGRESS REPORT V;  
APRIL 16-MAY 17, 1950. May 18, 1950. 9p.

Work has continued on calibration of flowmeters to be used in heat-transfer studies with Li. The Li melt-pot charging apparatus has been completed. An electromagnetic pump to be used in Li-erosion studies was designed and tested with Hg, and a second pump is now under construction. An isothermal erosion loop for operation with Li at 1000° F was designed and is ready for operation. Fire-extinguishing agents were tested for reaction with burning Li. An apparatus to compare the electrical resistivities of Li and stainless steel for purposes of flowmeter and pump design is now under construction. A sampling device for use in the test loop is described.

6.120 LIQUID LEVEL MEASUREMENT DEVICES

6.120 NUCLEAR INSTRUMENTATION

A Literature Search.

H. D. Raleigh and R. L. Scott, Comps. (Office of Technical Information Extension, AEC), May 1961, 153 p. (TID-3550) Rev. 1.

This bibliography includes 1,728 references on the design, construction, and application of instruments for radioactive environments. Includes liquid level gages.

NSA 15:22459

6.120 Low Impedance Bridge for the Measurement of Level of Liquid Metals  
J. Hyman, Jr.

Review of Scientific Instruments, Vol. 32, No. 7.  
July 1961, p. 833.

6.120 LEVEL TRANSDUCERS FOR LIQUID METALS

R. G. Affel, et al., Apr. 28, 1960, 45 p. (ORNL-2292).

Twenty-two resistance-type, continuously sensing level transducers for use in NaK pumps were constructed which gave high reliability (to 1400°F).

NSA 14:12703

6.120 DETECTING LIQUID METAL LEVELS

A. Stead and F. G. Latham. (United Kingdom Atomic Energy Authority, Capenhurst), Nuclear Power 5, 107-8 (1960) Dec.

An instrument was developed to measure the level of the NaK coolant for the Dounreay Fast Reactor in a sealed system. (More on abstract).

NSA 15:7551

6.120 NAA-SR-4195 (AI)

A Coil-Type Level Gauge for High Temperature Liquid Metals.

G. E. Turner. Nov. 15, 1959. 25p. Contract AT-11-1-GEN-8. OTS.

An electromagnetic liquid metal level device with an accuracy of  $\pm 1$  in., which requires no prior calibration and which will operate continuously at 1000°F, is described. The level gage can be replaced without opening the liquid metal system and is adaptable to automatic operation and recording.

NSA 14:4434

6.120 TID-3544

MR II DRIVER AND DETECTOR CIRCUIT FOR PRECISION SODIUM LEVEL PROBE.

J. Campbell. July 21, 1959. 8p. NAA-SR-Memo-4144 \$1.80(ph), \$1.80(mf) OTS.

NSA 13:21084

6.120 TID-3544

THERMOCOUPLE LIQUID LEVEL INDICATOR USED ON COLD TRAP STANDS. R. D.

Peak. Oct. 3, 1958. 6p. CF-58-10-13 \$1.80(ph), \$1.80(mf) OTS.

NSA 13:16936



- 6.120 Liquid Level Indicator by Zinn, W. H. and J. M. Harrer (to U. S. Atomic Energy Commission) U. S. Patent 2,791,119. May 7, 1957.

A remote liquid level indicator is described which is designed to accurately indicate the liquid level in a container which may be normally inaccessible, therefore simple dependable equipment in the tank is a necessity. Using a bubble gage in the container, an inert gas is forced to the bottom of the tank, the flow of gas being dependent on height of the liquid above gas orifice and the pressure of the gas. If the pressure is measured by a manometer with legs of unequal diameter, the gas pressure is transmitted to the thinner leg, and the force is multiplied in the thicker leg to act on an electrical transducer that gives an electrical indication to be read on a suitable meter.

NSA 11:9570

- 6.120 IGR-R/CA-255  
Davidson, D. F. (United Kingdom Atomic Energy Authority. Industrial Group. Capenhurst Works, Capenhurst, Ches., England.  
Measurement of Liquid-Metal Levels by the Effect of Eddy Currents on an Inductance. December 1957. 10 pages.

Remote-reading liquid-metal indicators were developed for the proposed sodium-cooled test loop in the Dounreay materials testing reactor. The principle used is the effect of eddy currents on the inductance of a coil. The coil is made in the form of a probe which is inserted in a vertical stainless steel pocket in the tank. Tests were made in a test rig, using liquid metals, to prove the instruments and to provide calibration curves. An approximately linear scale is obtained for an instrument in a tank 6 in. deep, but the instrument for a 3-in. tank needs a calibration. A standardizing facility allows for changes in the electronic circuits and enables a simple correction to be applied for temperature changes. A search probe was constructed to assist in the tests. It may prove to be a valuable instrument in some applications, since it is self-calibrating and independent of temperature.

- 6.120 NP-5840  
Progress Report No. 31 for October and November 1955. W. J. Posey, ed. Dec. 12, 1955. 72p. Contract NObs-65426.

Testing of the 3-Mw steam generators was continued. Level indicators for liquid Na, combined valve connect and disconnect, and AC induction pumps for liquid metals are described. Microfissure propagation has been observed as a result of quenching heated weld specimens with liquid Na. The feasibility of using impure  $N_2$  as a cover gas for sodium systems was demonstrated. Investigations were continued on the corrosion of Zr by liquid Na, the removal of Hg from sodium systems by amalgamation with Cu, and the radiation hazards arising from leaks in liquid metal systems.

- 6.120 NEPA-1377: BW-5204  
EROSION AND HEAT TRANSFER WITH LIQUID METALS: PROGRESS REPORT IV, MARCH 16-APRIL 15, 1950. H. G. Elrod, Jr. and Richard R. Fouse.  
Apr. 18, 1950. 9p.

Design and construction of an electromagnetic pump is discussed briefly. A charging unit for melting and supplying Li to various tests rigs and a simple inexpensive method of determining liquid levels at various points in the test apparatus are described.

QUARTERLY PROGRESS REPORT FOR JULY 1 - SEPTEMBER 30, 1953.  
UNCLASSIFIED SECTION). 57p.

Liquid Metal Heat Transfer. The objectives of this project are: (1) determination of the average film-heat-transfer coefficient for individual tubes in a tube bank for crossflow of Hg therein; (2) determination of circumferential variation of the coefficient around an individual tube; and (3) determination of pressure drop across the tube bank. With the completion of an automatic liquid-level control system, reasonably good pressure-drop data have been obtained. Pressure drops are about 5% below those expected on the basis of data on oil at lower Reynolds numbers and data on H<sub>2</sub>O at higher Reynolds numbers. This is believed due to non wetting of the stainless steel tubes by the Hg. Data obtained on tubes in the interior of the lattice show that, in general, the local coefficient is a maximum at the front of the tube decreases to a minimum at the rear of the tube, the rear value being 50% of that at the front. At a Reynolds number of 20,000, h varied from about 3000 Btu/(hr)(ft<sup>2</sup>)(°F) at the front of the tubes to about 1500 at the rear. Presently available data show that the average coefficient varies as the 0.55 power of the Reynolds number. At a Reynolds number of 80,000 h is about 5000. Liquid Metal and Heat Mass Transfer in a Spray Column. Hg and dilute amalgams have been selected for a study of simultaneous heat and mass transfer in a spray column. These metals will be dispersed in a non-metallic phase. Water and various organic liquids are being considered for this phase. Originally it had been planned to find a component which would dissolve as a pure solution in both phases. Since nothing was found to satisfy this requirement, a reaction between a metal dissolved in Hg and an oxidizing agent will be utilized for the mass-transfer study. The major heat-transfer resistance is expected to be in the nonmetallic phase. Preliminary calculations indicate that the heat-transfer rate will be so rapid that difficulty in obtaining good data is anticipated.

---

6.130 TEMPERATURE MEASUREMENT DEVICES

- 6.130 QUARTERLY STATUS REPORT ON LAMPRE PROGRAM FOR PERIOD ENDING  
NOVEMBER 20, 1960  
(LASL) Dec. 1960, 29 p. Contract W-7405-eng-26. (LAMS-2487)

Abstract refers to thermocouple failure, the cover gas system, and tantalum corrosion in sodium.

NSA 14:8345

- 6.130 THERMOCOUPLES FOR HIGH TEMPERATURE MEASUREMENT. A BIBLIOGRAPHY.  
A. C. Foskett. July 1959. 20p. BIS.  
AERE-Bib-125 United Kingdom Atomic Energy Authority. Research Group.  
Atomic Energy Research Establishment, Harwell, Berks, England.

A bibliography of 106 references covering the period 1954 to March 1959 is presented. The sources checked included Nuclear Science Abstracts, 1954 to 1959, Science Abstracts A and B, 1954 to 1958, Engineering Index, 1954 to 1957, Applied Science and Technology Index, 1957 to 1959, and indexes at AERE, Harwell. (J.E.D.) NSA 14-1-302

- 6.130 Pyrometer for Molten-Metal Temperatures  
Coretti, Paolo  
Ital. 487,404, December 2, 1953.

The pyrometer consists of a refractory container in which substance is placed which melts at a temperature slightly lower than the temperature to be measured. The container is connected to a manometer before it is introduced into the molten metal. From the vapor pressure-temperature curve of the melted substance in the container and manometer reading, the molten-metal temperature is determined. A water-jacket surrounds the manometer leads and provision is made for evacuating the manometer system before measurements are made. This minimizes the effect of permanent gases.

CA 50:16645

6.140 MERCURY BAROMETERS AND MANOMETERS

W. G. Brombacher, D. P. Johnson, and J. L. Cross  
(US Nat. Bur. Stand., Monograph, 1960, (8), 57 pp)

Designs of Hg barometers and manometers are briefly described, and the various design elements which may affect the achievable accuracy are discussed. Sources of error in measuring pressures, particularly for portable instruments, including scale, temp., gravity, capillarity, vacuum errors, and return gas column are detailed. Minimizing and corrective methods are given. Standard conditions are defined, and the properties of Hg listed. PFN

MA 28:903

6.140 Determination of Sodium Vapor Pressure at Temperatures from 880 to 1300 C

Kirillov, P. L. and Grachev, N. S.  
Inzhener, -Fiz. Zhur., Akad. Nauk Belorus, S.S.R.,  
No. 5, p. 3-7 (1959) May (In Russian)

A method for determining the saturated vapor pressure of sodium at 880 to 1300 C is described. The results are compared with the work of other authors. An equation is proposed for calculating saturated vapor pressure at various temperatures.

NSA 14:4291

6.140 AERE-R/R-2484

Naish, S. T. et al.  
United Kingdom Atomic Energy Authority, Research Group. Atomic  
Energy Research Establishment, Harwell, Berks, England.  
Instruments for the Measurement of Pressure and Differential  
Pressure of High Temperature Fluids. April 1958; 13p.

Instruments for the measurement of pressure and differential pressure are reviewed. At the time of writing no commercial instruments are considered suitable for operation in liquid bismuth or other fluids at high temperature in the range 200 to 550°C. Several prototype designs which have been tested for short periods are discussed. From these, two pressure transmitters and one differential pressure transmitter are recommended.

NSA 12:12513

6.140 Ingham, R. J. et al.

Manning, Maxwell, and Moore, Inc., Stratford, Connecticut  
High Temperature Pressure Measurement. Presented at Nuclear  
Engineering and Science Conference, held at Chicago, March 17 to 21,  
1958. Preprint 157, Session 15. New York, American Institute of  
Chemical Engineers, 1958; 27p.

A NaK filled diaphragm seal assembly has been developed which can be used up to 1500°F to measure pressure in liquid metal systems. The pressure can be shown on an indicating gauge connected by a suitable length of capillary to the seal. Both pneumatic and electric transmitters can be provided. Units have been made of several materials and with ranges of 0 to 100 to 0 to 400 psi. Minimum material thickness used in contact with the process fluid is 0.025 in. one ply. The change in calibration for temperatures between 70 and 1400°F is approximately 1% of full scale. Extensive testing has indicated good results.

6.140 ORNL-2483  
Miller, W. R.  
Oak Ridge National Laboratory, Tennessee  
High Temperature Pressure Transmitter Evaluation. July 21, 1958; 40p  
Contract W-7405-eng-26

Several designs of primary high-temperature pressure transmitters which would withstand the corrosive attack of liquid metals at elevated temperature and demonstrate the success of the design by operating for 3000 hr without maintenance were submitted. The instrument meeting the requirements was Model TN 1103 designed by the Taylor Instrument Co. The reasons for the choice were given.

NSA 12:12515

6.140 KAPL-1213  
SIR MARK A DOUBLE-DIAPHRAGM PRESSURE TRANSMITTER FOR THE PRIMARY COOLANT SYSTEM. A. J. Bialous, General Engineering Lab., General Electric Co. Notes compiled by G. G. Heard, Jr. (Knolls Atomic Power Lab.) Oct. 13, 1954. 27p. Contract W-31-109-eng-52.

A pneumatic force-balance type pressure transmitter has been developed and built for use in the SIR primary coolant system for operation up to 100 psig and 1000°F. In addition to design considerations, the choice of metals and welding and fabricating techniques required much study before suitable selections could be made. Performance characteristics under normal and abnormal operating conditions have been determined for the basic unit and its variations. Advantages and limitations of these units are discussed. Laboratory test and field reports indicate credible performance with good accuracy under trying system conditions.

6.140 KAPL-M-LBV-5  
Knolls Atomic Power Laboratory, Schenectady, N. Y.  
Electromagnetic Pressure Gage  
Vandenberg, L. B. and G. P. Hendricks  
July 18, 1952. 10p. Contract W-31-109-Eng-52

Development is described of a pressure gage for use with electromagnetic liquid metal pumps in which the current necessary to maintain equal and opposing force is proportional to the applied pressure to be measured. The pressures are maintained equal and opposite by means of an automatic liquid metal rheostat. A schematic sketch of the apparatus is included.

NSA 11:2437

6.140 ANL - 4554  
EXPERIMENTAL BREEDER REACTOR PROJECT. REPORT FOR THE PERIOD FEBRUARY 1, 1950, THROUGH MARCH 31, 1951. R. A. Cameron, B. C. Cerutti, L. J. Koch, H. V. Lichtenberger, D. F. McGinnis, M. Novick, E. N. Pettitt, H. E. Stanton, E. F. Stone, G. K. Whitham.  
April 1, 1951. Decl. Jan. 17, 1957. 60p.

The design of a pressure gauge system to show pressure changes in the fuel rods throughout the Experimental Breeder Reactor (CP-4) is described. Apparatus has been designed and built for filling the annulus in the lower section of the CP-4 fuel rod with NaK alloy. The procedure for adding NaK to fuel rods is described. The design of a totally enclosed liquid metal pump for the cooling circuit of the CP-4 is described in some detail. Results are given of a test of this pump in a NaK alloy coolant loop to determine its hydraulic characteristics. The design and operation of pressure transmitter unit for the reactor coolant system are described. Tests have been carried out to determine the heat transfer characteristics of a full size steam generator tube assembly under full power conditions. Design details and construction specifications of the tube are shown. Characteristics are shown of a gas circulating blower tested operating on air.

---

6.150 CORROSION-EROSION MEASUREMENT DEVICES

To be expanded in the supplement.

---

- 6.160 NAA-SR-5732, Detection Device for Hydrogen in Sodium  
Davis, K. A. (Jan 15, 1962)

A laboratory device capable of detecting trace amounts of hydrogen in liquid sodium has been developed. In loop operation the device extracts hydrogen from flowing sodium by allowing hydrogen diffusion through a nickel membrane. Ratio-of-rise measurements on a vacuum system placed on the exterior of the nickel barrier yields quantitative results. Spectrographic analysis of collected gas verifies the gas to be hydrogen. Sensitivity to detect 1.4 ppm (by weight) of hydrogen in sodium has been demonstrated.

NSA 16:7686

- 6.160 UNC-5028 Devel. of a Continuous Meter for O<sub>2</sub> in Na,  
Quarterly Report March 1-May 31, 1962. H. Steinmetz, United Nuclear Corp. Devel. Div., White Plains, N. Y. July 15, 1962, Contract AT(30-1)-2877 17p.

Previous experiments showed that it is possible to monitor the concentration of Na<sub>2</sub>O dissolved in liquid Na by an electrochemical method. The electrochemical cell consists of metal-metal oxide electrode, a calcium-stabilized ZrO electrolyte, and an electrode of Na containing the dissolved Na<sub>2</sub>O whose concentration the cell determines. In current experiments an electrochemical cell was operated satisfactorily for 1100 hrs at 500-600°F. It was found to give a good response to changes in O<sub>2</sub> conc. at temps. of 550-650 F. The response was poor at 750 F while at 900 F there was little or no response. Preliminary measurements yielded values for temp. coeff. of this cell in the range of -0.41 to -0.62 mv/°F. NSA 16:30602

- 6.160 APDA-149  
EVALUATION OF THE BLAKE SODIUM RESISTIVITY METER  
(Atomic Power Development Associates, Inc. Detroit)  
Oct. 15, 1962 Contract AT(11-1)865. 41 p.

An exploratory evaluation of the Blake resistivity meter, designed to monitor contamination level in liquid metal systems, was conducted. The meter tested was extensively in an experimental liquid-Na loop to establish signal stability under system variables, and it was successfully calibrated for the determination of oxide concentration in the 10-80 ppm range. Gas entrainment was detected at a concentration of 500 ppm by volume. It was concluded that the meter is reliable and suitable for service in radioactive environments. Recommendations are made for the improvement of signal stability as well as for extending the range of the meter to make it suitable for commercial applications above 600°F.

NSA 17:6382

- 6.160 DETERMINATION OF MICROGRAM AMOUNTS OF CARBON IN SODIUM  
(AWRE-O-62/62)  
J. Herrington (United Kingdom Atomic Energy Authority, Weapons Group Atomic Weapons Research Establishment, Aldermaston, Berks, England)  
Nov. 1962, 17 p.

A method of determining C present in Na as carbonate or elemental C in amounts equivalent to 5-25 microgram C is described. The method involves combustion to the oxides and carbon dioxide.

NSA 17:5948

- 6.160 NAA-SR-6986  
A DEVICE FOR CONTINUOUS DETECTION OF HYDROGEN IN SODIUM  
Strahl, H. (Atomics International. Div. of North American  
Aviation, Inc., Canoga Park, Calif.)  
May 31, 1962. Contract AT-11-1-GEN-8. 26p.

A device to detect the presence of H in Na was developed. As little as 1 ppm H (based on flowing Na inventory) can be detected in a flowing Na stream at 500 to 1200°F with response times in the order of 5 seconds. Such a device, installed in a Na-heated steam generator, would signal the presence of water in the Na resulting from a leak in the Na-water carrier.

NSA 16:20320

- 6.160 ELECTRICAL-RESISTIVITY METER MONITORS OXYGEN CONTENT OF LIQUID METALS  
L. R. Blake and A. R. Eames (United Kingdom Atomic Energy Authority, Caithness, Scotland), Nucleonics, 19:No. 5, 66; 68; 70; 72. (May 1961)

A device for continuously detecting and measuring gaseous impurities, mainly O but including C and H, entrained in liquid metals (Na, NaK, etc.). The meter is sensitive to impurity changes of 1 ppm, and is insensitive to temperature changes. It operates on the principle that impurities increase the resistivity of the metal.

NSA 15:16923

- 6.160 IMPROVEMENTS IN OR RELATING TO APPARATUS FOR INDICATING THE METAL OXIDE CONTENT OF A LIQUID METAL  
L. R. Blake (to United Kingdom Atomic Energy Authority), British Patent 873,912, Aug. 2, 1961.

An apparatus is described for measuring small changes in the electrical resistivity of a liquid metal due to the presence of metal oxide, impurities, or gas bubbles. The device consists of electrodes which cause the passage of an alternating current through the liquid metal in a metal pipe included in the pipework. There are probes for deriving two voltages, one being that due to the current through the liquid metal in the pipe and the other being a reference voltage which is derived from a sealed tube containing the same liquid metal but having a fixed oxide, impurity, and gas bubble content. (N.W.R.)

NSA 15:27835

- 6.160 PROGRESS RELATING TO CIVILIAN APPLICATIONS DURING MAY 1960  
BMI-1442 (Rev.)  
R. W. Dayton and C. R. Tipton, Jr. July 12, 1960. 100 p. OTS.

Includes mechanisms of wear and friction of various materials in Na, and new methods for determining low concentration of oxygen in Na.

NSA 14:19311

- 5.160 Liquid Metal Research (NDA)  
J. M. McKee, NASA TN-D-769, 1960.

Rocket-Nozzle cooling by Na, NaK - det. of O<sub>2</sub> content in Na - pumped Na loops.

NSA 15:13286

- 6.160 RESISTIVITY MONITOR TO INDICATE OXIDE CONTENT OF SODIUM  
L. R. Blake (Dounreay Expt. Reactor Est., Caithness, Scotland).  
Proc. Inst. Elec. Engrs. (London), Pt. A, 10T, 383,-94 (1960)Aug.

The electrical resistivity of Na or NaK is continuously measured while flowing at operating temperature in a pipe to provide an indication of impurity level, particularly of oxygen.

NSA 15:5199

- 6.160 THE DETERMINATION OF LOW OXYGEN CONCENTRATIONS IN SODIUM  
W. Jahns and G. Weidman (Siemens-Schuckertwerke AG., Erlangen,  
Germany). Nucleonik 1, 189-90 (1959) April (In German)

The possibility of determining low concentrations of oxygen in Na was discussed. A simple amalgam method was described and the solubility curve from it was given.

NSA 13:11653

- 6.160 A POSSIBLE GALVANIC CELL METHOD FOR MONITORING THE ACTIVITY OF OXYGEN IN A HOT-TRAPPED SODIUM COOLANT CIRCUIT  
(AERE-R-3037)  
G. W. Horsley, Atomic Energy Research Establishment, Harwell Banks, England), Nov. 1959, 15 p.

A hypothetical cell: Na (saturated with Na<sub>2</sub>O/anionic (O<sup>-</sup>) electrolyte/Na (unsaturated with Na<sub>2</sub>O), is examined from the theoretical standpoint assuming that the activity of dissolved oxygen in Na is proportional to its concentration. Provided that it is thermodynamically reversible, such a cell should give, for example, at 500°C changes in emf for changes in O<sub>2</sub> concentration from 1 to 2 ppm and 9 to 10 ppm, of ~23 and ~3 mv, respectively. Furthermore, fluctuations in temperature of ± 10°C at 500°C would in the concentration range of 1 to 10 ppm cause errors of about ± 12% in the concentration deduced from the cell voltage. The practical possibilities of building such a cell and incorporating it in a Na coolant circuit as a monitor are discussed.

NSA 15:10828

- 6.160 IGR-TM/D-090 UNCLASSIFIED  
United Kingdom Atomic Energy Authority, Industrial Group. Dounreay Works, Caithness, Scotland.  
Resistivity Meter to Indicate Oxygen Content of Liquid Metal.  
Blake, L. R.  
Apr. 1958. 25p.

An instrument for measurement of the oxygen content in liquid Na of NaK is described. The measurement is based on the electrical resistivity of the test solution. It is pointed out that the instrument is in the process of construction, and its characteristics and calibration are yet to be determined. (J.R.D.)

TID-1205 No. 15-13 942-1057

- 6.160 Measurement of Concentration of Tungsten Suspensions and Density of Liquid Sodium by Gamma Ray Absorption. J. S. Watt and K. R. Lawther, "Australian Atomic Energy Symposium, 1958"

Gamma ray absorption techniques were applied to measure the density of various media. In the case of liquid sodium contained in a stainless steel vessel, preliminary experiments indicate that the density may be measured to an accuracy of ± 0.01 gm/cc, and that 0.01 gm/cc transient changes in density occurring in a few seconds can be resolved.

A colorimetric method is outlined for determining cobalt in sodium metal, as little as 0.1 ppm cobalt can be determined.

NSA 14:1254

- 6.160 TID-7568 (Part 2)  
OPERATING EXPERIENCES WITH OXIDE MONITORS FOR SODIUM SYSTEMS.  
E. F. Batutis. P.24-32 of ANALYTICAL CHEMISTRY IN NUCLEAR REACTOR TECHNOLOGY. PART 2. INSTRUMENTATION, REMOTE CONTROL TECHNIQUES, AND NUCLEONICS SECOND CONFERENCE, GATLINBURG, TENNESSEE, September 29-October 1, 1958 9p. \$2.50(OTS).

TID 3544  
NSA 13:14247

- 6.160 See Also: 3.300 thru 3.340.

6.170 NaK PRECIPITATION INDICATOR TEST SYSTEM AND EXPERIMENTS TO DATE  
(NAA-SR-Memo-5472)

G. M. Kikin (AI) July 13, 1960. 37 p.

Solubilities and plugging of NaK in a test loop to 1000°F.

NSA 15:13924

6.170 DEVELOPMENT OF A RAPID-OPERATING PLUGGING METER

K. Davis (Atomics International, Div. of North American, Inc., Canoga Park, Calif.) Aug. 1, 1959, Contract AT(11-1)-GEN-8, 17 p. (NAA-SR-4537)

An air-cooled plugging meter for rapid determination of Na<sub>2</sub>O concentration in liquid Na was tested in an experimental system. Approximately 200 plugging tests were performed with results indicating good repeatability and a relatively fast operating time compared to other plugging meters. A typical operating time for making a determination with a system temperature of 725°F was 5 minutes.

NSA 15:18218

6.170 TID-7568: Pt 2 24-32 (1958), Operating Experiences with Oxide Monitors for Na Systems, by E. F. Batutis, MSA Res. Corp., Callery, Pa.

The control of oxides in an alkali metal heat-transfer system has been necessary from an operational and corrosion standpoint since the inception of these metals as heat-transfer media. Wet chemical methods for determining the degree of control are satisfactory for concentrations as low as 0.002 weight % O. Remote control monitors have been developed with similar detection limits. In these devices, oxide concentrations are determined by observing temperature at which oxide ppt. in a cooled by-pass stream, as indicated by an increase in resistance to flow. These so-called plugging indicators have given consistent and reliable results. The development and recent operational experience with these indicators in both large and small systems are also discussed. CA 57: 8387g

NSA 13: 14247

6.170 Inexpensive Way to Control Oxygen in Sodium Heat-Transfer Systems  
Gray, I. L. et al

Nucleonics 14, No. 10, 34-34 (1956)

Equipment is described for measuring and removing Na oxides from liquid Na and NaK when the latter is the heat-transfer media in nuclear power generation. A plugging indicator measures O<sub>2</sub> from 3-300 ppm. A stainless steel wire-mesh filter in a cold trap is used to reduce O<sub>2</sub> present as oxides to less than 10 ppm.

CA 50:16199

6.170 PURITY CONTROL IN SODIUM-COOLED REACTOR SYSTEMS.

Warren H. Bruggeman (Knolls Atomic Power Lab., Schenectady, N.Y.). A.I.Ch.E. Journal 2, 153-6 (1956) June.

Recent advances in purity control in sodium systems are covered. Emphasis is placed on results from the prototype SIR system as well as other unpublished data. Included are chemical and nuclear activation analyses of sodium, filtration data, and details and operation of cold traps and plugging indicators. (auth)

NSA 10:6631



6.170

HEAT TRANSFER ANALYSIS AND DESIGN OF A PLUGGING INDICATOR SYSTEM FOR SRE

(NAA-SR-Memo-1328)

H. L. Sletton (North American Aviation, Inc., Downey, Calif.)

April 1, 1955, 15 p.

The analysis was performed on a system comprising a counterflow, concentric-pipe economizer, heat exchanger, flowmeter, plug, and connecting pipe.

NSA 15: 14383

6.170

NP-5601

PROGRESS REPORT NO. 27 FOR FEBRUARY AND MARCH 1955. J. W. Mauteller, ed. Apr. 22, 1955. 62p. Contract NObs-65426

Tests on the Mark B 3000-Kw steam generator are described, including a circulating cold trap and plugging indicator, system cleaning, pump performance, NaK furnace tube failure, boiler water analysis, and heat transfer. Engineering studies are summarized on vent and drain line closures, NaK cross flow exchanger, development of EM pumps, pressure gages, wetting with alkali liquid metals, thermal shock, bellows testing, valve cleaning and testing, and thermal insulation tests in liquid Na. The depression of Na<sub>2</sub>O solubility in Na by K is discussed. Further studies on inhibition of mass transfer of radioactive stainless steel constituents in Na are described. The removal of residual radioactive Na with Na flushes was studied. Further results on radioactive leak contamination and the reactions of molten Zr in water are reported.

---

6.200 PUMPS

6.200

A SYSTEM OF CONVEYING LIQUIDS OR MIXTURES OF LIQUIDS

Jiri Drasky. British Patent 848,572, Sept. 21, 1960

A system for conveying liquid metals and radioactive liquids without the disadvantages of mechanical and electromagnetic pumps is described in which the vapors of the liquid are used to drive an injector-type pump in the circuit. Three configurations of the system are described for a liquid-metal-cooled reactor using a mixture of two metals with different boiling points (miscible and immiscible) and for pumping radioactive liquids from one container to another.

NSA 15:7469

6.200

Special Pumps for Nuclear Power Plants A. F. Erwin

(Allis Chalmers Mfg. Co., Milwaukee) Progress in Nuclear Eng.  
Sec IV, 3-29-39 1960.

The problems affecting main coolant pumps for current types of nuclear power plants are discussed; suitable types of pumps and drive for each type of plant are described with a summary of adv. and disadvantages of each.

NSA 16:12692

6.200

PWAC-292

EXPERIMENTAL CONTROL FOR TP-1 LIQUID METAL TURBO PUMP

P. V. Naples and S. F. Gladczuk Apr. 29, 1960, 23 p.  
(Pratt & Whitney Aircraft Div., United Aircraft Corp., Middletown, Conn.) Contract NOas-58-662-c.

Initial tests have started, recommendations for modifications and further testing are included.

NSA 14:15726

- 6.200 DESIGN AND OPERATION OF PUMPS FOR SODIUM AND SODIUM POTASSIUM ALLOYS. P. L. Kirillov, V. A. Kusnetsov, N. M. Turchin, and Yu. V. Fedoseev. Atomnaya Energiya, Vol. 7, No. 1, pp 11-17, July 1959. Submitted February 10, 1959.
- 6.200 PUMPS FOR LIQUID METALS USED FOR NUCLEAR TECHNOLOGY. Dr. R. Berndt. German, per, Maschinen bau technik, Vol. IX, No. 8, pp 417-21, 1960.
- 6.200 A DEVICE FOR PUMPING LIQUID METAL. V. T. Burtsev. A. M. Samarin, et. al., Byulleten Izobreteniy, No. 13, p. 49. 1960. ATIC MCL-965/1 + 2.
- 6.200 NAA-SR-6303  
THE SNAP II POWER CONVERSION SYSTEM - TOPICAL REPORT NO. 11. ORBITAL FORCE FIELD BOILING AND CONDENSING EXPERIMENT. TAPCO ER-4443., P. E. Grevstad, 15 January 1960. Prepared under Subcontract N843FS-101221 for A.I.

This report provides the basis for a program to investigate the characteristics of Rankine space power plants in the zero gravity aspect of the environment of space. It justifies the need for this work by presenting the expected effects on Rankine space power plants. Discussions of experimental techniques for studying these phenomena show that this information can be obtained rapidly and economically. (AGN Lib. 2-2296)

- 6.200 BNL-756  
DEVELOPMENT OF SNAP-2 HEAT TRANSFER COMPONENTS  
W. D. Leonard and R. D. Keen, Atomics International, Second Annual High Temperature Liquid Metal Heat Transfer Technology Meeting, May 17-18, 1962

Description of SNAP-2 system and its major components, in both the NaK and Mercury Loops. The progress and revisions of the developmental components is described.

- 6.200 COMPACT REACTOR POWER PLANT WITH COMBINATION HEAT EXCHANGER - THERMOELECTRIC PUMP  
E. A. Luebke and L. B. Vandenberg, (Knolls Atomic Power Lab., Schenectady, N.Y.) July 7, 1954. Decl. with Deletions Feb. 19, 1960. Contract W-31-109-eng-52. 19 p.

A compact reactor power plant is described in which the reactor proper is located within a cylindrical heat exchanger. The pumping action in the liquid-metal-cooled system is obtained in combination with the heat exchanger function. By interposing thermoelements, a large thermoelectric current is generated in the heat exchanger by the temperature gradient normally existing between hot and cold tubes. With suitable pole pieces, the current produces a perpendicular magnetic field and develops sufficient force on the liquid metal for the desired pumping action. NSA 15:19031

- 6.200 BNL-756  
LIQUID METAL RESEARCH AT NASA-LEWIS RESEARCH CENTER  
James P. Lewis, Lewis Research Center, Cleveland, Ohio  
Second Annual High Temperature Liquid Metal Heat Transfer Technology Meeting, BNL, May 17 and 18, 1962

The paper outlines the major liquid metals research and development efforts at Lewis Research Center. The work includes: a Two-Phase Sodium Loop for flashing sodium vapor; the Sodium Turbine Facility using refractory metals; Pump Test Facilities including one low pressure K pump and one high pressure Na pump; Alkali Metal Heat Transfer Facility using EM pumps and Cb-12r above 1500° F and type 316 stainless below; A Space Radiator and Condenser Facility using a NaK loop for boiling potassium; Bearing and Seal Studies using liquid Na environments; Mercury Programs relative to the radiator problem in zero gravity similar to SNAP VIII conditions; and several Materials Support Programs directed to advanced materials and refractory metals for all alkali metals, and Hg loop corrosion.

- 6.200 Experience With Russian Liquid Metal Pumps. P. L. Kirrilov, V. A. Kuznetsov, N. M. Turchin and Yu. M. Fedoseyev. Engineers' Digest, v. 21, June 1960, p. 115-116, 114. (From Atomnaya Energiya, v. 7, p. 11-17.)

Special designs of centrifugal and electromagnetic pumps for circulating liquid metals such as Na and NaK at temperatures of 300 and 500°C. Efficiency and operation life and effects of liquid metal corrosion are discussed. (w13d)

- 6.200 Selection of Liquid-Metal Pumps by Hammitt, F. G. (Univ. of Michigan, Ann Arbor) Chem. Eng. Progr. 53, 249-53 (1957).

The design and development of large-scale, liquid-metal circulating pumps such as would be suited to application in nuclear power plants have been investigated. Fluid dynamic problems-cavitation and erosion damage to the structural components at the high relative velocities obtained in the pump impeller - were the particular concern.

CA 51:10139

- 6.200 Pumping of Liquid Metals  
Barnes, A. H. from "Progress in Nuclear Energy, Series 4, Technology and Engineering," Vol. 1, edited by R. Hurst and S. McLain, McGraw-Hill, New York, 1956. Chapter 5, pp. 165-76.

This paper discusses the engineering design features of mechanical and electromagnetic pumps used for liquid metals. Direct current and alternating current pumps are covered.

- 6.200 ORNL-2012 (Pts. I, II, III, Del.)  
AIRCRAFT NUCLEAR PROPULSION PROJECT QUARTERLY PROGRESS REPORT FOR PERIOD ENDING DECEMBER 10, 1955  
A. W. Savolainen, ed. March 11, 1956 Decl. with deletions  
Oct. 22, 1959, 206 p. Contract W-7405-eng-26. OTS.

Includes ART Na pump, a pump for NaK to 1400°F, NaK heat exchangers, and NaK radiators.

NSA 14:6042

- 6.200 PUMPS AND VALVES  
J. F. Cage, Jr., and G. D. Collins  
The Reactor Handbook, Vol. 2, Engineering, Chap. 2.7, p. 342, 1955

Mechanical and electro-magnetic pumps for Na-NaK service.

- 6.200 Cavitation in a Venturi Tube Passing NaK. (78%K.) Alloy at 200-300 C  
Crofts, T.I.M.  
Great Brit. Windscale Works, Sellafield Cumb., England  
RDB(W)/TN-160 Aug. 1954. 18p. (FRDC/P-72)

Tests with NaK (78% K) eutectic alloy at 200 to 300 C in a venturi tube show that cavitation takes place at pressures approaching absolute zero. The effects of gas entrainment and also of a magnetic field were studied.

NSA 13:10377

- 6.200 CF-54-8-225  
Oak Ridge National Lab., Tenn.  
Some Observations Made on Cavitating Sodium Flow in a Venturi by J. M. Trummel. Aug. 31, 1954. 10p Contract W-7405-eng-26.

Cavitating sodium flow was obtained in the venturi of an isothermal loop at temperatures from 1215 to 1475°F. Cavitation was detected in three ways: by observing the minimum venturi throat pressure, by observing the loop pressure drop, and by listening to the flow noise. Cavitation occurred promptly when venturi throat pressure was reduced to within about 1.5 psia of vapor pressure. Venturi wall damage due to cavitation has not been determined.

NSA 11:13710

- 6.200 NP-3658; BW-5039  
WATER AND NaK TESTS OF A PROTOTYPE LIQUID METAL PUMP. O. H. Baker  
and J. J. Owens. Jan. 25, 1952. 54p.

Water and NaK tests of a prototype liquid-metal pump having a capacity of 3625 gpm at a 125-ft head are described. The assembly of the circuit build to test the pump with liquid metal is discussed. This pump was described in detail in Report No. 5308, and a liquid-metal fire resulting from failure of the motor bearings was reported in Report No. 5040. Performance data obtained from the water tests, dynamometer tests, and liquid-metal tests are included in the present report. Hydraulic and electrical characteristics were satisfactory. Several conclusions and recommendations relative to the pump and test equipment are enumerated.

- 6.200 Failure of Liquid Metal Pump and Resulting Damage to Pump  
And Test Facility. James J. Owens. Jan. 5, 1951. 59p.  
NP-3380

The large (2900 gpm) Byron Jackson liquid metal pump, which was under test, failed and the resulting leakage of NaK alloy to the atmosphere caused a fire. This failure was caused primarily by one of the ball bearings which broke and pierced the stainless steel liner. An account of events leading up to the fire, a description and analysis of the pump and bearing failure, an account of the pump damage, and an estimate of the cost of repair are included in the report. Also included are descriptions of the cleaning of the pump and circuit, the disassembly of the pump, and a number of recommendations.

- 6.200 See Also: 2.300 thru 2.350.
- 

6.210 ELECTROMAGNETIC

- 6.210 IMPROVEMENTS IN OR RELATING TO ELECTROMAGNETIC LIQUID METAL  
PUMPING SYSTEMS  
Blake, Leslie Reginald  
(To United Kingdom Atomic Energy Authority)  
British Patent 905,940. Sept. 12, 1962

An electromagnetic pump for liquid metals is designed which is of the type comprising primary and secondary ducts in an air gap in a magnetic circuit. When liquid metal is pumped through the primary duct, an emf is generated to provide an electromagnetic pumping action in the secondary duct. The ducts are longitudinally shaped to increase in width and decrease in thickness going away from the center of the magnetic circuit, in order to minimize efficiency losses due to by-pass current. (D.L.C.)

- 6.210 NaK Loop Equipment  
NAA-SR-5244 SNAP 2 Reactor Pump Development Program (Radial Gap  
Permanent-Magnet Pump), Sudar, S. (Sept. 1961).

A compact electromagnetic pump utilizing a rotating permanent magnet with radial gap was developed for possible application to the SNAP 2 Reactor coolant system. The pump was designed for circulation of NaK at 1000°K and 11.2 gpm with a developed pressure of 3 psi, operation at 40,000 RPM, minimum weight and size, and high reliability. The performance characteristics of four pump models were measured in a 1000° F NaK test loop and compared with design predictions. The capability of the pump design concept was demonstrated, though further development work is needed to meet the SNAP-2 pump requirements. A flow capacity of 6.8 gpm at 1000° F with head of 3 psi at 4000 RPM. Pump weight was 3 lbs.

NSA 16:11816

FLOW IN DIRECT-CURRENT ELECTROMAGNETIC PUMPS

Rossow, Vernon J. NASA, Ames Research Center, Moffett Field, Calif. In National Research Council. Magneto-Fluid Dynamics. Proc. of a Symposium sponsored by IUTAM/NAS-NRC, Williamsburg, Va. and Wash. D. C., Jan. 1960. Repr. from Rev. of Modern Phys., v. 32, no. 4, Oct. 1960. p. 987-991. 2 refs. (See N62-15768 15-21)

A simple model has been devised that permits one to investigate how the departure of the electric and magnetic fields from their one-dimensional character affects the flow of an electrically conducting fluid. The effect of the ends of the electric and magnetic fields on the flow is studied theoretically and experimentally by means of the direct-current electromagnetic pump. The pump impresses an electric and a magnetic field across the channel to produce a body force on the fluid in a direction along the channel. In order to realize a simple configuration for the experiment, the electrodes are assumed to be at constant potential and to have a length equal to the channel width. A copper sulfate salt solution is used as the working fluid that flows through a clear plastic channel under the action of the electric and magnetic fields. The flow velocity ranges from 1 to 4 in./sec under the influence of a 0.4- to 1.6-amp current and a 4000-gauss magnetic field. Since the induced fields are each about  $10^{-3}$  times smaller than the imposed fields, the analysis is greatly simplified because the effect of the field motions on the imposed electromagnetic fields is negligible. Classical methods can then be used to find the electric-current distribution in the flow field. These results, taken together with the corresponding results for the magnetic field, permit the direct calculation of the body forces in the fluid. Results demonstrated that the finite length of the electromagnetic fields can cause sizable deviations from one-dimensional flow. It is possible, however, to correct for these end effects by either shaping the magnetic field or varying its intensity to fit the electric field, or by combinations of both techniques. (V.D.S.)

6.210

TEST OF LINEAR INDUCTION ELECTROMAGNETIC PUMP FOR HNP

(NAA-SR-Memo-5777)

R. S. Baker, A.I., Oct. 26, 1960, 4 p.

Investigations to determine the characteristics of electromagnetic pumps constructed for the Hallam Nuclear Power Facility are described. Resulting data are incorporated in curves of pressure vs flow, and efficiency vs flow obtained with Na at 600° F.

NSA 15:7512

6.210

IS-188

PERFORMANCE CHARACTERISTICS OF AN ELECTROMAGNETIC PUMP

D. H. Thompson and R. W. Fisher

Ames Lab., Ames, Iowa, Aug. 1960. 55 p. Contract W-7405-eng-82, OTS.

Includes wetting of the pump cell...

NSA 14:25586

6.210

NAA-SR-4388

A LINEAR INDUCTION PUMP FOR LIQUID METALS

R. S. Baker, Jan..15, 1960 25 p. Contract AT-11-1-GEN-8. OTS. (AI)

... To circulate Na at 600° F, 342 gpm with 6.2 psi (No seals or moving parts).

NSA 14:7485

- 6.210 DESIGN OF TWO ELECTROMAGNETIC PUMPS FOR NaK  
R. S. Baker and W. J. Fraser. Mar. 25, 1960, 11 p. (AI)

Two types of E.M. pumps, d-c conduction and a-c linear induction, were designed to pump NaK at 650 F at a rate of 354 gpm with a developed pressure of 20 psi (NAA-SR-Memo-5106).

NSA 14:17950

- 6.210 NaK Pump Evaluation  
Baker, R. S. and Fraser, W. J.  
Atomics International, Div. of North American Aviation, Inc.,  
Canoga Park, Calif. NAA-SR-Memo-5004, February 18, 1960, 30 p.

Four types of electromagnetic pumps were considered, from an efficiency and weight standpoint, for the task of pumping 11 gpm of 78% K NaK having a temperature of 1000 F with a pressure rise across the pump of 4 psi. The d-c conduction electromagnetic pump appeared to be the most suitable. Characteristics of all four types are listed.

NSA 15:4084

- 6.210 Wound-Rotor Electromagnetic Pump for NaK  
Baker, R. S. and Fraser, W. J.  
Atomics International, Div. of North American Aviation, Inc.,  
Canoga Park, Calif., NAA-SR-Memo-5433, 22 June 1960, 15 p.

Design sheets were prepared for an electromagnetic wound-rotor pump developing 4 psi at 13 gpm pumping 1000 F NaK. Computations showed an efficiency of 2.8% and a weight of 71 lb. The design sheets describe the method of designing this type of pump and calculation of pump performance.

NSA 15:4085

- 6.210 JPRS-2397  
On the Thermal Processes in an Electromagnetic Induction Pump.  
J. Lielpeteris. Translated from Latvijas PSR Zinatni Akad. Vestis,  
No. 9, 91-100 (1959). 13p. OTS.

An analysis of thermal processes in an induction pump of planar construction was made. Basic schemes of the thermal processes are discussed. The heat exchange process between the liquid metal and the walls is discussed for pumps with forced cooling systems, with and without compensation for heat loss by the liquid metal, and for pumps without forced cooling. Calculations on steady and transient thermal processes were made. NSA 14:11708

- 6.210 ELECTRO-MAGNETIC PUMPS FOR LIQUID METALS  
L. R. Blake (United Kingdom Atomic Energy Authority)  
Reactor Technol. 1, 65-76 (1959)

As a guide to pump selection, about a dozen of the more important type are described.

NSA 14:379

- 6.210 Design of 3400 GPM, 40 PSI Linear Induction Pump for the 250 MWE Overflow Reactor  
Baker, R. S.  
Atomic International Div., North American Aviation, Inc.,  
NAA-SR-Memo-4413 (Rev. 1), Canoga Park, Calif.  
July 16, 1959, 14p.

Design of a linear induction pump for the 250 MWE advanced sodium graphite reactor is described. The pump develops 3400 gpm at 40 psi using sodium at 625 F. NSA 14:15725

- 6.210 APPLIED MAGNETO-HYDRODYNAMICS  
 Proceedings of the Institute of Physics, No. 8, Trudy Instituta Fiziki, VIII, Riga, Izd-Vo Akademii Nauk Latvyskoy SSR, 132 pp 1956.
- Theory, problems, phenomena, and electromagnetic processes in induction pumps for liquid metal.
- 6.210 ON THE MODELING OF MAGNETOHYDRODYNAMIC EFFECTS IN LIQUID METALS  
 I. M. Kirko Trudy Inst. Fiz. Ak Nauk Latviiskoi SSR, Vol. 8, pp 3-24, 1956.
- 6.210 ELECTROMAGNETIC PROCESSES IN INDUCTION PUMPS FOR LIQUID METALS  
 I. A. Tyvtin and E. K. Yankop. Trudy Inst. Fiz. Ak Nauk Latviiskoi SSR, Vol. 8, pp 65-80, 1956. Infor-search Translation TIFL 56 (8)/PM-5.
- 6.210 ELECTROMAGNETIC PUMPS FOR LIQUID METALS. (Brief Survey of the Present State of Development from Published Material)  
 I. A. Tyvtin and E. K. Yankop. Trudy Inst. Fiz. Ak Nauk Latviiskoi SSR, Vol. 8, pp. 24-48, 1956. Infosearch Translation TIFL 56 (8)/PM-2.
- 6.210 END EFFECTS IN LINEAR INDUCTION PUMPS. L. Yu, Ul'manis.  
 Trudy Inst. Fiz. Ak Nauk Latviiskoi SSR, Vol. 8, pp 81-94, 1956. Infosearch Translation TIFL 56(8)/PM-6.
- 6.210 INTRODUCTION TO THE THEORY OF INDUCTION PUMPS.  
 I. A. Tyvtin. Trudy Inst. In-ta Fiz. AN Latv. SSR, Vol. 8, pp 49-58, 1956, Translation: F-TS-9981/V.
- 6.210 FLOW - VELOCITY DISTRIBUTION AND MAGNETO-HYDRODYNAMIC PRESSURE LOSSES IN THE THROAT OF A COAXIAL INDUCTION PUMP.  
 E. K. Yankop. Zinatnraksti. Latv. Univ. Uch. Zap. Latv. un-t, Vol. 10, pp 15-20, 1957. Translation from: Referativnyy Zhurnal, Mekhanika, 1958, No. 9, p. 85.
- 6.210 ELECTROMAGNETIC PUMP FOR LIQUID METALS. H. H. Agena. Atomkern-Energiy, Vol. 3, pp 249-255, July 1958. In German.
- 6.210 THE MAGNETIC FIELD OF THE INDUCTORS IN LINEAR ELECTROMAGNETIC PUMPS. A. I. Vol'dek. Izvestiya Vysshikh Uchebnykh Zavedniy, Elektromekhanika, No. 12, pp 14-20, 1958. Submitted 12/28/58. Association: Chair of Electrification of Industrial Undertakings, Tallin Polytechnical Institute.
- 6.210 ELECTROMAGNETIC PUMPS FOR LIQUID METALS. I. A. Tyutin. Riga. Izdavo A. N. Latviyskoy SSR, 113 pp. 1959. Institute of Physics, A.S. Latv. SSR.
- 6.210 THERMAL PROCESSES IN ELECTROMAGNETIC INDUCTION PUMPS. Ya. Liyelpeter  
 Physics Institute, Academy of Sciences Latvian SSR, Riga, Isvestiya Akademii Nauk Latviyskoy SSR, No. 9, pp 91-100, 1959
- 6.210 ELECTROMAGNETIC PUMPS. I. A. Tyvtin Riga, AN Latv. SSR, 116 pp 1959. (Mentions Author's Certificate No. 1175), October 11, 1960, issued to L. A. Verte for liquid metal pumps operating at temperatures of 1500°C.
- 6.210 VELOCITY DISTRIBUTION AND MAGNETO HYDRAULIC PRESSURE LOSSES IN A RECTANGULAR CHANNEL. Yu. A. Birzvalk and I. A. Tyvtin  
 Trudy Inst. Fiz. Ak Nauk Latviiskoi SSR, Vol. 8, pp 59-63, 1956. Infosearch Translation TIFL 56(8)/PM-4.

- 6.210 THE PROBLEM OF A CONDUCTING SPHERE, IN A MOVING MAGNETIC FIELD  
Yu. K. Krumin. Trudy Instituta Fiziki Riga, pp 130-138, 1956.  
Translation F-TS-9981/V.
- 6.210 SINGLE PHASE ALTERNATING CURRENT PUMPS (A.C. FARADAY PUMPS).  
E. K. Yankop. Trudy Inst. Fiz. Ak. Nauk Latvinskoi SSR,  
Vol. 8, pp 107-121, 1956. Infosearch Translation TIFL 56(8)/PM-8.
- 6.210 CALCULATION METHODS FOR LIQUID METAL INDUCTION PUMPS. Ya Ya.  
Liyelpeter and I. A. Tyvtin Trudy Inst. Fiz. Ak. Nauk Latvinskoi  
SSR, Vol. 8, pp 95-106, 1956. Infosearch Translation TIFL  
56(8)/PM-7.
- 6.210 ELECTROMAGNETIC PUMPS WITHOUT MOVING PARTS FOR THE CONVEYANCE  
OF LIQUID METALS. J. Steiner and H. Hohn. Chem. Eng. Tech.,  
Vol. 28, No. 6, pp. 405-410. June 1956. In German.
- 6.210 THE PULSATING COMPONENT OF THE MAGNETIC FIELD OF INDUCTION  
MOTORS AND OF PUMPS WITH INTERRUPTED MAGNETIC CIRCUIT.  
A. I. Vol'dek. Nauch. Dok. Vysshey shkoly. Elektro. i.  
avtomatika, No. 2, pp 130-9, 1959. Submitted January 4, 1959.
- 6.210 ELECTROMAGNETIC PHENOMENA IN FLAT INDUCTION PUMPS FOR MOLTEN  
METAL. N. M. Okhremenko. Elektrichestvo, No. 3, pp 48-55,  
1960. Submitted August 14, 1959.
- 6.210 THE LONGITUDINAL EDGE EFFECT IN THE SECONDARY CIRCUIT OF INDUCTION  
MACHINES AND METAL PUMPS WITH OPEN MAGNETIC CIRCUIT.  
A. I. Vol'dek. Izvestiya Vysshikh Uchebyykh Zavedeniy,  
Elektro-mekhanika, No. 3, pp 3-11, 1960. Submitted October 24,  
1959.
- 6.210 ELECTROMAGNETIC PUMPS FOR LIQUID METALS. A. I. Vol'dek.  
Elektrichestvo, No. 5, pp 22-27, 1960. Submitted December 7,  
1959.
- 6.210 ELECTROMAGNETIC PUMPS FOR LIQUID METALS. N. M. Okhremenko.  
Elektrichestvo, pp 48-55, 1960
- 6.210 VOLTAGE AND CURRENT ASYMMETRY IN INDUCTION MACHINES AND PUMPS  
WITH OPEN MAGNETIC CIRCUITS. A. I. Vol'dek Izvestiya  
Vysshikh Ucheb ny kh Zaved niy, Elektromekhanika, No. 5  
pp 3-9, 1960. Submitted March 2, 1960
- 6.210 EXPERIENCE IN DEVELOPING ELECTROMAGNETIC PUMPS AT THE INSTITUTE OF  
PHYSICS OF THE ACADEMY OF SCIENCES OF THE LATVIAN SSR  
P. G. Kirillov, et al. Translated from Voprosy Magnit.  
Gidrodinamiki i Dinamiki Plazmy, Trudy Konf., Akad. Nauk Latv. S.S.R.,  
Inst. Fiz., Riga. 1958, 262-8 (1959).

Several electrical, magnetic, and hydrodynamic approximations are described that may be used in the design of electromagnetic pumps of the induction and conduction types. The characteristics of plane-linear, helical, and direct-current pumps constructed using these approximations are outlined. Pump cooling methods are discussed. (T.F.H.)

NSA 15:32849

- 6.210 Hilditch, J. A. S. (British Thomson-Houston Co., Ltd., Rugby, Eng.)  
The Electromagnetic Pumping of Liquid Metals.  
Atomics and Nuclear Energy 9, 125-7 (1958) April.

In the second part of a series on electromagnetic pumping of liquid metals, the design and characteristics of the a-c conduction pump and the induction pump are discussed. Possible future developments in the pumping of liquid metals are described.

NSA 12:9135



- 6.210 ORNL-3168  
Oak Ridge National Laboratory, Tenn.  
Compatibility of Pump Lubricants with Alkali Metals and Molten Fluoride Salts by G. Goldberg A.S. Meyer, Jr. and J. C. White, Jan 14, 1957.  
Decl. Sept. 19, 1957, 16p. Contract W-7405-eng-26.

This report includes a description of an apparatus and a detailed procedure for testing the compatibility of pump lubricants with alkali metals and molten fluoride salts. Results are given for the reaction between certain pump lubricants at 200°F and molten sodium metal and molten fluoride salts at 1100°F

NSA 12:3653

- 6.210 ANALYSIS OF EXPERIMENTAL D. C. PUMP PERFORMANCE AND THEORY OF DESIGN.  
D. A. Watt. July 1957. 59p. (AERE-R/R-2275)

The performance characteristics of an experimental d-c pump operated on Hg are interpreted in terms of an equivalent resistance net-work. The method of deriving this from the results is explained, and it is shown that a special term must be included to allow for the difference between the apparent e.m.f. after wall and end loss have been eliminated and the full value of the e.m.f. generated between the electrodes. This difference is about 12% in the experimental design of length/breadth ratio  $c/b = 7/3$ . Shaped pole pieces were used to extend and grade the field in the end regions. It is confirmed that the cases of greatest field extension had the smallest end effect loss. The results are expressed in terms of non-dimensional ratios and it is shown that after subtracting the main wall loss the maximum liquid efficiency is 57%. This is not dependent on resistivity and so would be applicable to Na in a geometrically similar design. Wall losses are more significant with Hg than they would be with Na, but the maximum developed efficiency of the experimental pump is 44%. Formulas are suggested for limited extrapolation of numerical coefficients peculiar to the geometry of this pump.

- 6.210 AERE-R/R-2274  
Gt. Brit. Atomic Energy Research Establishment, Harwell, Berks, England  
Tests on an Experimental D. C. Pump for Liquid Metals by D. A. Watt  
et al. May 1957. 52p.

The experimental equipment and techniques of construction and measurements are briefly described. A comprehensive survey of pump performance with graded field to control and current losses is given, together with some results for a simple baffle system. Field grading gives the better result, the maximum efficiency being near 40% with Hg in an 18/8 stainless steel channel with 25 gpm flow. It is considered that a baffle system of improved form may have some advantage in pumps of smaller length/width ratio. For the pump described the ratio,  $c/b = 7/3$ . Gas entrainment tests are described: these showed only small changes in pump performance. Hydraulic friction losses from water flow tests are recorded.

NSA 12:213

- 6.210 AERE-R/M-144  
Atomic Energy Research Establishment, Gt. Brit. Harwell, Berks, England  
Design of Travelling Field Induction Pumps for Liquid Metals by  
D. A. Watt. Sept. 1957. 13p.

Theory and examples of design for maximum rate of pressure rise are given. It is shown that while designs for low resistivity, low density liquid metals optimized do not give the maximum possible rate of head rise the condition for this is not greatly different. A technique for rapidly deriving the condition for maximum rate of head rise is illustrated and the basic principles discussed. For high resistivity liquid metals it is explained that an approach limiting flow speed and gap flux density would be needed, although performance is inevitably reduced and the D.C. pump offers a much better power rating and efficiency.

NSA 12:3652

- 6.210 NP-5912  
CALCULATION OF DEVELOPED PRESSURE AND FLUID POWER IN LINEAR POLYPHASE  
INDUCTION LIQUID METAL PUMPS. Technical Report No. 48. R. S. Baker.  
Mar. 24, 1956. 67p. Contract NObs-65426.

The following factors which affect the performance of linear polyphase induction liquid metal pumps are discussed; frequency of the power source; speed of the traveling field; electrical power losses due to harmonic losses of the traveling magnetic field; and "end effects" due to the stationary fields at each end of the pump. Formulas are given for calculating the pressure developed in liquid metal, by the action of a traveling magnetic field in a linear polyphase induction pump, and the electrical power loss in the liquid metal caused by the traveling field. Equations for obtaining maximum shut-off pressure by varying pump dimensions are also presented. An example of the application of these equations to pump design is included.

- 6.210 AERE-ED/R-1844  
A Single Phase Annular Induction Pump for Liquid Metals  
Gt. Brit. Atomic Energy Research Establishment  
Watt, D. A. January 21, 1953. Decl. Jan. 17, 1956. 44p.

This is a declassified version of AERE-CE/R-1090

An electrodeless single-phase a-c liquid metal pump with combined transformer is described. The principle of operation is discussed and mathematical theory deduced. A design study for a pump producing 60 ft heat rise in a sodium circuit at 400°C with flow rate of 1100 gpm is included. This will have an annular pumping channel of nearly 12 in. mean diameter, 1/2 in. internal width and length 2 1/2 in. An electrical efficiency of 30 to 35% can be expected with an overall efficiency of 20 to 25%. The pump is designed to be operated from 415-volt single-phase means; about 110 kva will be required with an overall power factor near 0.5. A note is appended on the general theory of a-c conduction pumps.

- 6.210 KAPL-M-LT-3  
Knolls Atomic Power Lab., Schenectady, N. Y.  
Calculations on a D. C. Electromagnetic Pump  
Tonks, Lewi  
June 16, 1948. Decl. Feb. 8, 1956. 10p. Contract W-31-109-eng-52

An analysis was made of the electromechanics of a centrifugal d-c-actuated liquid metal pump. A uniform axial magnetic field assures constancy of angular velocity through the whirling chamber.

NSA 11:2464

- 6.210 Electromagnetic Pumps for Liquid Metals by Watt, D. A. (Atomic Energy Research Establishment, Harwell, Berks.)  
Engr. 181, No. 4703, 264-8 (1956) April.

The elementary consideration affecting the design and application of compensated d-c and traveling field a-c pumps for liquid metals are given. A brief survey of electromagnetic pumping equipment developed by U.K.A.E.A. is included.

NSA 11:5305

- 6.210 APPLIED MAGNETIC HYDRODYNAMICS  
Translated from Trans. of the Inst. of Physics, Academy of Sciences,  
Latvian S.S.R., Riga, 1956, 142p. OTS.

The papers included in this volume are: magnetic hydrodynamic phenomena in liquid metals; electrodynamic pumps for liquid metals; theory of induction pumps, and others. (NP-tr-355)

NSA 14:12292

- 6.210 AERE-ED/R-1856  
Gt. Brit. Atomic Energy Research Establishment, Harwell, Berks, England  
A. C. Liquid Metal Pumps for Laboratory Use  
Watt, D. A. March 19, 1953. Revised Jan. 24, 1956. 33 p.

Two types of single phase a-c electromagnetic pump for liquid metals are described, a leakage reactance model and a combined pump and transformer. The NaK alloy test rig is briefly described and methods of pump construction detailed. Test results are curves for pumping NaK alloy at temperatures below 70 C are included, and it is shown that the combined form is the more effective pump. One of these models with a single loop secondary winding had a maximum efficiency of 11% with output 10 gals/min. at 13 lb/in.<sup>2</sup> pressure rise, input 650 watts, 9.0/7.5 amps at 180/195 volts. A maximum pressure rise of nearly 30 lb/in. is recorded for the first model of this form.

NSA 10:11171

- 6.210 Electromagnetic Pumps for Liquid Metals  
Anonymous  
Metallurgia 53, 277-8 (1956). June.

Several types of electromagnetic pumps are described for use with liquid metals of high and low density, viscosity and resistivity.

- 6.210 Electromagnetic Pumps Without Moving Parts for Pumping Liquid Metals  
Steiner, Julius and Hans Hohn  
Chem.-Ing.-Tech. 28, 405-10 (1956).

A comprehensive treatise of the mathematical principles and presentations of experimental data.

- 6.210 AERE-Inf/Bib-93 (4th ed.)  
Gt. Brit. Atomic Energy Research Establishment, Harwell, Berks, England  
Electromagnetic Pumps and Flowmeters. A Bibliography of Literature References and Readily Available Reports by Greenhill, M. and C. S. Sabel, comps, October 1956. 1 Op. 55 references

NSA 11:6345

- 6.210 KAPL-1367  
THEORY AND ENGINEERING APPLICATION OF A PRACTICAL THERMOELECTRIC ELECTROMAGNETIC (TEM) PUMP. Lewi Tonks. Aug. 1, 1955. 28p. Contract W-31-109-Eng-52.

Calculations show that thermoelectricity can have a practical power application to the electromagnetic pumping of liquid metal coolant through a nuclear reactor and its associated primary heat exchanger with the thermoelectric elements and circuit as an integral part of the exchanger. Here the basic theory of such a device is developed, including the parasitic circulation of current within each fluid metal channel, the varying temperature difference over the length of the exchanger, and the modification of theory consequent to having the fluid metal in pipes. Possible causes of instability are discussed and how to attack their analysis is indicated, but no analysis is made. The theory is applied to a specific engineering design.

- 6.210 AERE-Inf/Bib-93(3rd Ed.)  
Gt. Brit. Atomic Energy Research Establishment, Harwell, Berks, England.  
ELECTROMAGNETIC PUMPS AND FLOWMETERS.  
A Bibliography. M. Greenhill. 1955. 5p.

Available unclassified reports from the Geneva Conference, the A.E.R.E. and the A.E.C. are listed in this bibliography.

NSA-10-2699

- 6.210 ISC-547  
AN ELECTRO-MAGNETIC PUMP AND HEATING TRANSFORMER FOR HIGH TEMPERATURE LIQUID METALS. G. R. Winders and R. W. Fisher. Dec. 6, 1954. 15p. Contract W-7405-eng-82.

Details of a linear electromagnetic induction pump and heating transformer for circulating Mg-Th alloy at 1000°C are given.

- 6.210 REPORT NO. 1 ON 1000 KW SYSTEM  
Tidball, R. A., F. L. Mangold and S. N. Tower  
Mine Safety Appliances Company, Callery, Penna.  
Memo Report No. 49, October 15, 1953. 14p.

The 1000-kw heat transfer system was designed to test pilot plant size liquid metal system components at temperatures to 1400°F. The test program was divided into phases: transferring heat to air and transferring heat to boiling water. Two liquid metal systems to prevent exposing the tubes of the liquid metal heater to full steam pressure in event of a failure of the steam generating equipment were used. The air cooled system is shown schematically. The NaK was circulated by a rotary magnet pump, through a flowmeter into the NaK heater. The discharge from the heater was piped to the tube side of the intermediate heat exchanger, and returned to the pump. Sodium was circulated by a DC conduction pump, through the flowmeter, the shell side of the intermediate heat exchanger, a swing check valve to the sodium cooler. Discharge of the sodium cooler passed through a stop valve, an a-c conduction pump to the suction of the d-c pump. The sodium was cooled by an air blast over finned tubes. Both NaK and sodium systems were fitted with diffusion type cold traps, expansion tanks, and emergency dump tanks. The sodium piping was fitted with tubular heaters (strapped to the outer surface) to preheat the piping before charging. Tests of the major components of this unit at various loads and temperatures are reported.

- 6.210 RDB(W)-TN-92  
Operating Experience With No. 1 400 GPM Flat Linear Induction Pump. T. I. M. Crofts. Sept. 1953.

Operation of a three-phase electromagnetic pump for 360 hours is reported. Experience gained in this operation with NaK was used when modifications to a second pump rig was made. The effectiveness of these modifications is shown by completion of 1,000 hours operation on the second rig.  
NSA 14:4437

- 6.210 WIAP-M-30  
Westinghouse Electric Corporation. Industrial (atomic power) group.  
Phg. A 50 Kw DC Electromagnetic Pump for Liquid Metal Application  
Jones, A. R. (1953). Changed from Official Use Only May 17, 1956. 17p.

The results of the study and design of a pump to handle three thousand gallons per minute of liquid Na at 600°F pumping against a developed head of 100 ft. While Na and the other liquid metals do not differ radically from water in density or viscosity they do have certain characteristics which indicate changes in the component designs in systems for their handling.

NSA 11:1061

- 6.210 KAPL-M-JJM-1  
Knolls Atomic Power Lab., Schenectady, N. Y.  
An Investigation of Electromagnetic Pump Failures by Marquin, J. J.  
May 3, 1954. 14p. Contract W-31-109-Eng-52

An investigation is presented on the unusual number of small AC electromagnetic pump failures which have occurred in an attempt to make recommendations with regard to design changes in the pumps and to establish a proper mounting and operating procedure for using the pumps.

NSA 11:2449

- 6.210 KAPL-1177  
Knolls Atomic Power Lab., Schenectady, N. Y.  
Ceramic Insulation for Electromagnetic Pump Coils  
Sowman, H. G. and C. W. Krystyniak  
June 1, 1954. Changed from Official Use Only June 26, 1956. 26p.  
Contract W-31-109-Eng-52

A unique method of electrically insulating coils of an electromagnetic pump is described. Glass coatings on the Cu conductors were used as a means of turn to turn insulation. The insulation was composed of inorganic materials only. Successful tests were carried out at coil temperatures of approximately 500°C. Electrical resistances were found to be adequate and the thermal shock properties excellent. In addition, the glass coating provided considerable protection against oxidation for the copper conductors.

NSA 11:2475

- 6.210 KAPL-M-FNS-6  
Knolls Atomic Power Lab., Schenectady, N. Y.  
Use of a D-C Electromagnetic Pump as a Throttling Device in a Sodium System Schell, F. N. Aug. 13, 1953. 11p. Contract W-31-109-Eng-52

Operation of a d-c pump as a dynamic brake (magnetic drag) in a Na system proved successful. The Na flow from the 50 gpm test pump was reduced by 26 percent and the pressure at the inlet of the test pump was lowered from 15 psia to 2.7 psia. A comparison between the performance of the d-c unit as a pump and as a generator is presented.

NSA 10:10958

- 6.210 KAPL-M-LBV-5  
Knolls Atomic Power Laboratory, Schenectady, N. Y.  
Electromagnetic Pressure Gage  
Vandenberg, L. B. and G. P. Hendricks  
July 18, 1952. 10p. Contract W-31-109-Eng-52

Development is described of a pressure gage for use with electromagnetic liquid metal pumps in which the current necessary to maintain equal and opposing force is proportional to the applied pressure to be measured. The pressures are maintained equal and opposite by means of an automatic liquid metal rheostat. A schematic sketch of the apparatus is included.

NSA 11:2437

- 6.210 REACTOR ENGINEERING AND SERVICES DIVISION. QUARTERLY REPORT (FOR) DECEMBER 1, 1950 THROUGH FEBRUARY 28, 1951. W. P. Bigler. Mar. 14, 1951. Dec1. Dec. 10, 1955. 29p. Contract W-31-109-eng-38.  
ANL-4596 \$4.80(ph OTS); \$2.70(mf OTS).

An electromagnetic pump, its head-capacity characteristics when pumping NaK, and its current supply are illustrated. The recommended building design for the Argonne Research Reactor is discussed. Heat transfer and fluid flow problems connected with D<sub>2</sub>O flow and the effect of the chilled water system on pile reactivity are discussed in some detail, as is pile control by water expulsion. Curves of heat production in U fuel rods after shutdown are given, measurements of the resonance integral of massive Th shapes are reported, and the status of an experiment on change in length of U metal under irradiation is summarized briefly.

- 6.210 AECD-3459, KAPL-619  
DESCRIPTION AND TEST RESULTS OF A 400-GPM LIQUID METAL INDUCTION PUMP.  
J. F. Cage, Jr. and E. H. Schoch. Oct. 23, 1951. Dec1. Nov. 6, 1952. 93p.

This report is a description of a round, 400-gpm, a-c electromagnetic pump which was manufactured and tested to determine the feasibility of its mechanical design and the accuracy of the theoretical analysis. The objective was to provide a pump, without bearings, packing, shaft seals, or moving parts of any kind, which would be capable of pumping 750° F Na at flows up to 400 gpm against a head of approximately 40 psi for extended periods of time without leakage or other cause for maintenance.

- 6.210 NEPA-1377; BW-5204  
EROSION AND HEAT TRANSFER WITH LIQUID METALS: PROGRESS REPORT IV, MARCH 16-APRIL 15, 1950. H. G. Elrod, Jr. and Richard R. Fouse.  
Apr. 18, 1950. 9p.

Design and construction of an electromagnetic pump is discussed briefly. A charging unit for melting and supplying Li to various tests rigs and a simple inexpensive method of determining liquid levels at various points in the test apparatus are described.

- 6.210 Knolls Atomic Power Lab.  
ELECTROMAGNETIC PUMPS FOR HIGH TEMPERATURE LIQUID METAL,  
by J. F. Cage, Jr. (nd) 31p. (AECU-2282)

A summary report is presented describing electromagnetic pumps for liquid metals. The pumps vary in size and application from small-scale laboratory pumps to those suitable for circulating liquid metal in a nuclear reactor power plant. The design and performance characteristics of the a-c and d-c Faraday types, helicalflow induction type, and the linear induction pump are described.

NSA 7-135

- 6.210 AECD-3460; KAPL-568  
TEST OF 1200-GPM LINEAR A-C ELECTROMAGNETIC PUMP. John Barnard and  
G. D. Collins. May 23, 1951. Decl. No. 6, 1952, 56p.

Design and performance data are given for a straightline, a-c induction electromagnetic pump to be used for pumping 1250-gpm of liquid Na at a pressure of 38 psi at temperatures up to 750°F.

- 6.210 NEPA-1423; BW-5205  
EROSION AND HEAT TRANSFER WITH LIQUID METALS; PROGRESS REPORT V;  
APRIL 16-MAY 17, 1950. May 18, 1950. 9p.

Work has continued on calibration of flowmeters to be used in heat-transfer studies with Li. The Li melt-pot charging apparatus has been completed. An electromagnetic pump to be used in Li-erosion studies was designed and tested with Hg, and a second pump is now under construction. An isothermal erosion loop for operation with Li at 1000°F was designed and is ready for operation. Fire-extinguishing agents were tested for reaction with burning Li. An apparatus to compare the electrical resistivities of Li and stainless steel for purposes of flowmeter and pump design is now under construction. A sampling device for use in the test loop is described.

- 6.210 Result of Analysis of AC Electromagnetic Pump. J. F. Cage, Jr. and  
G. D. Collins. Oct. 17, 1949. 43p (GEL-56; R49GL148)

The expected performance of an electromagnetic pump suitable for pumping 1400 gpm of liquid Na is analyzed, using theoretical considerations, induction-motor design data, and all available empirical data.

- 6.210 ANL-4238  
Report for the Period March 1, 1948 Thru November 30, 1948.  
Reactor Engineering Division. W. H. Zinn, director. Feb. 3,  
1949. Decl. Mar. 28, 1957. 67p.

Detailed design and operational data on a NaK circulation system is presented. Design information on electromagnetic pumps is included. 39 figures.

---

6.220 PUMPS FOR HIGH TEMPERATURE LIQUID SYSTEMS

Savage, H. W., and Grindel, A. G.  
 (Oak Ridge Nat. Lab., Tenn.). Paper No. 1743-61. Presented at  
 "Space-Nuclear Conference, May 3-5, 1961, Gatlinburg, Tennessee."

High temperature pumps are required for several mobile and stationary nuclear reactor power plant applications using sodium, NaK alloy, or fused salt as coolants. Some of these pumps must operate at temperatures above 1500°F for periods well in excess of 20,000 hours. The incidence of failures is low. A summary and evaluation of the incentives, courses of development, present status, and applicability of the various types of pumps used in the past or now under development are given, which indicate design features that may be of use in developing equipment for space vehicles. The designs and special features of these pumps, primarily centrifugal pumps, are discussed. These inherent in bearings, seals, lubrication, hydraulic performance, cavitation inception, choices of materials, fabrication procedures, drives, liquid expansion, and size and maintenance considerations.

NSA 15:23649

6.220 Sodium Reactor Experiment: Pump Development

Cygan, R. (North American Aviation, Inc., Canoga Park, Calif.)  
 United States Atomic Energy Commission (NAA-SR-1662) 37p. (1957).

The full-scale prototype centrifugal pump used for development tests is described. Measurements of cooling requirements, pressure drop, torque, temperature distribution and reliability of the freeze seals employed in the pump are reported to Na temperatures up to 1200°F. Several localized corrosion and (or) erosion which occurred on the suction side of the case, made from ASTM-A157-C6, is described. It is attributed in part to localized carburization resulting from leakage of bearing-lubricating oil and Tetralin coolant into the circulating Na, and resulting formation of  $\text{Na}_2\text{C}_2$ . The use of sealed bearings packed with radiation-resistant grease is recommended. Tetralin is preferred to water as coolant only because of the explosion hazard attending any leakage of water into Na. Inward leakage of tetralin results in a multiplicity of reactions, not all known. An increase in system pressure together with formation of  $\text{C}_x\text{H}_y$ , C, and  $\text{Na}_2\text{C}_2$  have been observed. The C tends to coat the inside metal surfaces; the other reaction products raise the melting point of the mixture progressively. On solidification gray coke-like masses form which give off  $\text{C}_2\text{H}_2$ -like fumes in moist air. Several recommendations are made with regard to pump design. Clearances of 0.050-0.070 inch, on 10-inch diameter, between the impeller and pump-housing wear rings are recommended for use up to 1200°F. For the shaft freeze seal, an annulus of Na with a conical outer surface is favored. The freeze seal operates below the melting point of Na and acts as a diffusion-type cold trap which preferentially removes  $\text{Na}_2\text{O}$  from the Na stream. Anticonvection rings are recommended to reduce the cooling load on the static freeze seal used to close off the pump case to head casting joints.

CA 51:6235

6.220 ORNL-CF-54-8-234

Oak Ridge School of Reactor Technology, Tenn. Farris, E. S.  
Summary of High Temperature Liquid Metal, Fused Salt Pump Development  
Work in the ORNL-ANP Project for the Period July 1950-January 1954.  
 August 1954. Decl. Nov. 15, 1957. 98p.

All of the information available on high-temperature pumps originally reported in the ANP quarterly reports is summarized. The development program was more of a seal development than a specific pump program. Frozen seals of various kinds were tried and for many commercial applications would be perfectly satisfactory. For application in a system such as the ARE, operation of the frozen seal pump is questionable. A gas-sealed pump was developed and is expected to be entirely adequate for a system like the ARE.

NSA 12:13908

- 6.220 Performance Of HNPF Prototype Free-Surface Sodium Pump  
Atz, R. W.  
Atomics International, Div. of North American Aviation, Inc.,  
Canoga Park, Calif., NAA-SR-4336, June 30, 1960, 26 p.  
Contract AT-11-1-GEN-8

A free-surface centrifugal pump, incorporating a hydraulic bearing running in sodium, was operated at the conditions required for service in the Hallam Power Reactor. After difficulties arising from inadequate shaft clearances were alleviated the pump performed properly at a flow rate of 7200 gpm of 945 F sodium at 150-ft head. Results indicate that this pump should perform satisfactorily in the Hallam plant.

NSA 15:4078

- 6.220 Testing of HNPF Freeze-Seal Pump  
Atz, R. W.  
Atomics International, Div. of North American Aviation, Inc.,  
Canoga Park, Calif.  
NAA-SR-4387, Nov. 1, 1960, 48 p. Contract AT-11-1-GEN-8

A centrifugal pump performed adequately at a flow rate of 7200 gpm of 945 F sodium at a 150-ft head. A two-region freeze seal was developed and used successfully as a shaft seal on this pump. The results indicate that this pump could perform satisfactorily in the Hallam Power Reactor.

NSA 15:4079

- 6.220 THE SNAPP II POWER CONVERSION SYSTEM TOPICAL REPORT NO. 10, SODIUM PUMP DESIGN AND TESTING  
Snoke, Betty A., and Tiltins, Janis, (Thompson Ramo Wooldridge Inc., Cleveland). (NAA-SR-6300) Aug. 5, 1960. For A.I. Div. of North American Aviation, Inc., Canoga Park, Calif. Contract AT(11-1)-GEN-8, Sub-con. N843-FS-101221. 61p. ER-4106

SNAP II is the designation for a 3 kw nuclear auxiliary power unit for utilization in a satellite vehicle. The SNAP II system consists of a reactor source which utilizes a mercury Rankine engine for power conversion. Design details and test data for the primary fluid reactor coolant pump used to transfer heat from the reactor to the mercury boiler are described.

NSA 16:3970

- 6.220 TRANSFER OF MERCURY  
Medvedev, S. A.  
Tsvetnye Metally 31, No. 1, 79-80-(1958)

Vortex-type pumps Mark 1B-0, 9 were shown to be suitable for pumping Hg. The laws of hydrodynamic similarity are valid for the above pumps when working with H<sub>2</sub>O or Hg. Pump characteristics are given.

CA 52:10655g

- 6.220 NP-8458  
General Electric Co. Light Military Electronics Dept.,  
Schenectady, N. Y.  
Research on Liquid Metals as Power Transmission Fluids. Progress  
Report No. 4 (for) June 1, 1959 to February 1, 1960. R. C. Kumpitsch.  
Feb. 1960. 27p. Project No. 8-(1-7331). Contract AF33(616)-5917.

Continued effort was applied in establishing a 1 GPM 3000 psi, 1000°F, NaK-77 (liquid metal) flow test loop. This test loop, when completed, will be used in the research of determining the feasibility of using liquid metals as high temperature, hydraulic power transmission fluids. Progress is reported toward completion of the test equipment including completion of the low pressure portion (console) of the test loop, and installation of the high pressure NaK pump mounting and speed drive fixture in the inert atmosphere glove box. The high pressure NaK pump is currently 60 percent complete. Delivery of the unit is scheduled for April 15, 1960. Three components were added to the liquid metals test loop. These components consist of two over-pressure relief valves and a high temperature liquid metals servo. (For preceding period see NP-8457.) (auth)

NSA 14:11704



General Electric Co. Light Military Electronics Dept.,  
Schenectady, N. Y.

Research on Liquid Metals as Power Transmission Fluids. Progress  
Report No. 3 (for) March 1, 1959 to June 1, 1959. R. C. Kumpitsch.  
June 1959. 26p. Project No. 8-(1-7331). Contract AF33(616)-5917.

The research effort, during this report period, on liquid metals as power transmission fluids was concerned with establishing a 1-gpm, 3000-psi, 1000°F, NaK-77 test flow loop. The low-pressure portion (console) of the test loop has been completely assembled. A control panel for operation of the loop was fabricated. The "console" was installed in the liquid metals test area and completely instrumented, with exception to the loop's low-pressure sensing and recording equipment. The design of the high-pressure NaK pump mounting and speed drive fixture for the inert atmosphere "glove box" was completed. This mixture is currently being constructed. Continuing progress is being made on the manufacture of the high pressure-temperature NaK staged gear pump. No improvement in the delivery schedule for this pump has been obtained. Difficulty is being experienced in the procurement of correctly fabricated carbide material for this NaK pump. Negotiations are currently underway with both the pump and material vendors to resolve the problem. The revised liquid metals program schedule is included. (auth)

NSA 14:11703

A Gas Shaft Seal for the HNPf Sodium Pump

Admire, B. W. and Naylor, F. S.

Atomics International, Div. of North American Aviation, Inc.,  
Canoga Park, California, NAA-SR-Memo-2616, 30 June 1958, 6p.

Lip type, oil labyrinth gas seals were tested for use on Hallam Power Reactor sodium pumps with a 5-in. diameter rotating shaft. The seals were not recommended for use owing to excess helium leakage and short life.

NSA 15:408

Freeze-Seal Valves and Pumps

Cygan, R. and A. M. Stelle (North American Aviation, Inc.), Canoga Park, Calif. Chem. Eng. Progr. 52, 157-9 (1956). April

Freeze seals have been developed for sealing stationary and rotating shafts affording a simple means of adapting commercial equipment for use in high-temperature liquid-metal systems. Several designs for sealing sodium at temperatures up to 1200°F have been satisfactorily tested. Under different operating conditions cooling loads, torque, and temperature distribution were measured. Locating the freeze-seal away from the high-temperature region allows the formation of an annulus of frozen metal around the shaft with small cooling loads.

NP-7391

Performance of a Frozen Sodium Seal on a 120 GPM Duriron

Centrifugal Pump, Heckel, V. K. and King, E. C., Mine Safety Appliances Co., Callery, Pa., June 28, 1954, 15p, Contract NObs-65426.

Experimental data indicated that the flow and pressure of the centrifugal pump met the design capacity. The motor was found to be inadequate in that seal friction accounted for 40% of the input. The second test indicated that seal leakage during the operation was not excessive and the pump could not be started and stopped without raising the seal temperature.

NSA 13:12678

INITIAL TEST OF SODIUM PUMP AND INSTRUMENT LOOP. R. Cygan. Dec. 1, 1954. Dec1. No. 6, 1958. 35p. (NAA-SR-Memo-1178) \$3.30(ph), \$2.40(mf) OTS.

NSA 13:11500  
TID 3544

- 6.220 CENTRIFUGAL PUMP FOR AMALGAM. L. I. Gel'man, Energomashinostroenie, No. 9, Sept. 1956.
- 6.220 IMPROVING THE ANTI-CAVITATION PROPERTIES OF CENTRIFUGAL PUMP STAGES BY MEANS OF PRE-CONNECTED AXIAL IMPELLERS. V. I. Dumov. Teploenergetika (Thermal Power) Vol. 4, No. 4, pp 16-21, April 1957. Association: Kalvga Turbine Works.
- 6.220 CONCERNING THE MECHANISM OF CAVITATION IN CENTRIFUGAL PUMPS. N. S. Yershow. Iz Vysshikh Ucheb Zaved, Aviats Tekhn. Vol. II, No. 3, pp 57-63, 1959. ATIC MCL-1156/1.
- 6.220 ON TWO FEATURES OF THE CAVITATION CHARACTERISTICS OF A CENTRIFUGAL PUMP WITH A FEATHER TYPE IMPELLER AND DIVIDED DISCHARGE OF FLUID. I. V. Dumov and M. A. Peshkin. Izvestiya Vysshikh Uchebnykh Zavedeniy, Aviat-Sionnaya Tekhnika, No. 2, pp 147-150, 1959. Submitted January 12, 1959. ATIC MCL-1158/1.
- 6.220 MND-P-2378  
SNAP I POWER CONVERSION SYSTEM PUMP DEVELOPMENT. Period Covered: February 1, 1957 to June 30, 1959. TAPCO (ER-4053)  
E. S. Kovalcik and D. S. Reemsnyder, June 1960.

A four-vaned impeller pump supplemented by a jet boost stage was selected for development to meet final design requirements. Information on other designs, pump test facilities, and conclusions are included.

NSA 14:26037

- 6.220 TID-1170  
AERE-ED/M-28 (Rpt: OFFICIAL USE ONLY)  
Gt. Brit. Atomic Energy Research Establishment. Harwell, Berks, England. TESTS ON A LIQUID METAL CENTRIFUGAL PUMP.  
Naish, S. T. Oct. 1955. 14p.

The tests described were carried out to provide data for the design of centrifugal pumps for liquid metals and to investigate the effect on the pump characteristics of pumping liquids of widely differing densities. (auth)

- 6.220 THE DEVELOPMENT AND OPERATION OF CENTRIFUGAL PUMPS FOR LIQUID METALS AND FUSED SALTS AT 1100-1500° F  
W. F. Boudreau, A. G. Grindell, and H. W. Savage (Oak Ridge National Lab., Tenn.). Nuclear Sci and Eng. 2 No. 1, Suppl., 17-18 (1959) June

Four centrifugal pumps developed at ORNL for circulating Na, NaK and molten salts at temperatures up to 1500° F are described. The pumps were built with capacities of 5-6, 60-150, 500-700, and 1200-1500 gpm. The design heads range from 40 to 375 ft. All are sump type pumps, and they utilize centrifugal impellers and volutes of conventional geometric design. A vertical pump shaft with the impeller overhung at the lower end is supported in a nearly conventional bearing housing. Drive motors are located above or at one side and external to the bearing housing. (W.D.M.)

NSA 13 19-17327

- 6.220 ISOTHERMAL PUMP LOOP. R. Keen. Oct. 22, 1952.  
Decl. Dec. 5, 1955. 10p. Contract (AT-11-1-GEN-8). AECD-3831;  
NAA-SR-Memo-469). \$3.30(ph OTS); \$2.40(mf OTS).

A centrifugal pump built entirely of graphite and capable of handling liquid metals in the temperature region of 1000° C is described. The pump was designed to meet the requirements of a high-temperature reactor.

- 6.220 Liquid Metal Seal for Sodium Pump Shafts  
Carniglia, S. C.  
Atomics International, Div. North American Aviation, Inc.,  
Canoga Park, Calif., NAA-SR-Memo-2184. October 4, 1957, 7p.

Several liquid metal sealants were investigated for sodium-pump shafts.

NSA 15:4080

- 6.220 NP-6458  
RESEARCH ON LIQUID METALS AS POWER TRANSMISSION FLUIDS. Quarterly Progress Report No. 4 (for) June to September 1957. R. C. Kumpitsch, J. Huthsteiner, and D. Lombardo. Sept. 1, 1957. 27p.

The General Electric Co. has provided a new facility in which to determine the feasibility of using Na-K alloys, especially NaK 77, as a power transmission fluid for high temperature applications. The facility, complete with an integral disposal and clean-up area, provides a more efficient, clean, confined, and safe location in which to undertake this development. Operation in the new test area is scheduled for 16 September 1957. Initial tests conducted with the single cylinder NaK test pump revealed that modification and improvement of this equipment was necessary to insure consistent 3000 psi 1000° F operation. All design changes being made to the single piston pump tester are described in detail in the report. An investigation was conducted to determine the most suitable high temperature wear tester commercially available for preliminary screening of materials and for evaluating the lubricity effects of additives in NaK 77. Several of the wear testers being considered have been evaluated. This investigation has not been completed. The results to date are included in this report. Future effort will be directed toward getting the Single Piston NaK Pump tester into operation and the selection and purchase of the most desirable wear tester.

- 6.220 DEVELOPMENT OF CENTRIFUGAL PUMPS FOR OPERATION WITH LIQUID METALS AND MOLTEN SALTS AT 1100 - 1500° F (ORNL)  
A. G. Grindell, W. F. Boudreau, and H. W. Savage  
Nuclear Science and Engineering 7, 83-91 (1960) Jan.

Sump-type centrifugal pumps ranging in capacity from 2 to 1500 gpm were developed for circulating liquid metals at temperatures up to 1500° F in metallurgical, heat transfer, and reactor experiments. Each of these pumps uses a nearly conventional bearing assembly to support a vertical tank containing the high temperature liquid and an inert cover gas. Drive motors and lubrication equipment are external to the pump proper. Seven different models of sump-type pumps were manufactured and about 400,000 hr of operation were accumulated in the temperature range of 1100 to 1500° F.

NSA 14:7493

- 6.220 ORNL-2544  
Correlation of Cavitation Inception Data for a Centrifugal Pump Operating in Water and in Sodium Potassium Alloy (NaK)  
Grindell, A. G.  
Union Carbide Corp. Oak Ridge National Lab., Oak Ridge, Tenn.  
N.D. Contract W-7405-eng-26. 34p

NSA 13:2993

- 6.220 TID-1170-14  
AERE-ED/M-31 (Rpt: OFFICIAL USE ONLY)  
Gt. Brit. Atomic Energy Research Establishment, Harwell, Berks, England.  
TESTS ON IMPELLERS FOR A LIQUID METAL CENTRIFUGAL PUMP, Reid, H. A.  
Oct. 1956. 26p.

The tests were carried out to determine the most suitable type of impeller for use with a Bowl Type centrifugal pump and to provide data for its design as a Bi pump. (auth)

- 6.220 AERE-R/M-95  
Gt. Brit. Atomic Energy Research Establishment, Harwell, Berks,  
England, The Design and Development of a Liquid Metals Mechanical  
Pump by F. L. Speed and K. A. Tomblin. Sept. 1953. 16p.

Mechanical pumps for use on liquid metals work can be broadly classified into the following types: totally enclosed pump employing internal bearings operating in liquid metal and driven by some form of magnetic coupling and, conventional pump with external oil lubricated bearings overhung impeller and a shaft seal unit. It was agreed that the former type of mechanical pump was a more attractive solution for large scale plant. However, as considerable development work both on bearings operating in liquid metal and the method of drive was required, it was decided to design a pump of the latter type which appeared to offer a quick solution for laboratory use. A description of the work carried out in developing such a pump for a particular laboratory application is presented.

NSA 12:212

- 6.220 Steele, O. P.  
Westinghouse Electric Corp., Cheswick, Penna.  
High Temperature Mechanical "Canned Motor" Liquid Metal Pumps.  
Presented at Nuclear Engineering and Science Conference, held at  
Chicago, March 17 to 21, 1958. Preprint 76, Session 2. New York,  
American Institute of Chemical Engineers, 1958; 18p.

Studies of certain type nuclear power plants to employ superheated steam has placed emphasis on sodium and sodium-potassium alloys as high-temperature heat transfer mediums. After careful consideration of all various pumping problems for handling these materials, a mechanical "canned motor" pump was considered to have the greatest success potential. The design problems and their solutions are outlined. Pumps of this type have already been produced in sizes to 700 horsepower and for stream temperatures to 1500°F.

NSA 12:11414

- 6.220 Sodium Reactor Experiment Pump Development. R. Cygan.  
Jan. 1, 1957. 37p. (NAA-SR-1662)

Operation of a 6 X 8 X 13 freeze seal type centrifugal pump has been carried out at Na temperatures up to 1200°F. Measurements have been made of cooling requirements, pressure drop, torque, temperature distribution, and reliability of the freeze seals employed in the pump. Design and operational techniques are described. This pump design appears promising for large-scale liquid-metal systems.

- 6.220 Mercury Bellows Pump  
Robinson, E. S., A. C. Briesmeister and B. B. McInteer (to U.S.  
Atomic Energy Comm.) U.S. Patent 2,775,399. December 25, 1956.

A liquid piston gas pump design that isolates and minimizes the gas contained in the pump, has a high pumping rate, and requires a minimum amount of power for operation is described. The pumping chamber, containing tappet-operated inlet and outlet valves is situated above a mechanical driven bellows. As the bellows is compressed Hg is forced into the pumping chamber compressing and expelling virtually all of the contained gas. Tappets attached to the bellows operate the valves in the proper sequence.

Nuclear Notes for Industry dated 4/26/57

- 6.220 KAPL-M-GDC-6  
Knolls Atomic Power Lab., Schenectady, N. Y.  
Experimental Work on Class C Insulation for Liquid Metal Pumps  
Collins, G. D., August 15, 1952. Decl. June 18, 1956. 7p.  
Contract W-31-109-Eng-52

The development of a program to learn the use of class C insulating materials in liquid metal pumps is presented. The specification for the insulation assembly is given. The fabrication of insulated coil assemblies using tapes, binders, and enamels and the insulation of conductors placed in slots using enamels, ceramic spacers, and fillers, and fugitive or permanent binders were investigated.

NSA 11:2892

- 6.220 MECHANICAL LIQUID METAL PUMPS IN THE ALPLAUS (GENIE) HEAT TRANSFER SYSTEM. P. M. Clark. Nov. 1, 1951, 31p. (KAPL-635). Mech. Eng. 75, 615-18(1953).

The design and operation of the mechanical liquid metal pumps in the Alplaus (Genie) heat-transfer system are described. The pumps are centrifugal pumps with long overhung rotors. The pumping elements are contained in drain tanks which return pump leakage to the storage tanks. The drain tanks, which are pressurized with an inert gas, are sealed at the pump shaft with a face-type rotary shaft seal. The development of the seal is described. The highest liquid-metal operating temperature at the pump has been 800°F.

#### 6.300 VALVES

- 6.300 BNL-756  
DEVELOPMENT OF SNAP-2 HEAT TRANSFER COMPONENTS  
W. D. Leonard and R. D. Keen, Atomics International, Second Annual High Temperature Liquid Metal Heat Transfer Technology Meeting, May 17-18, 1962

Description of SNAP-2 system and its major components, in both the NaK and Mercury Loops. The progress and revisions of the developmental components is described.

- 6.300 DESIGN, PRODUCTION AND TESTING OF NUCLEAR VALVES FOR LIQUID COOLANT REACTORS  
Valen, A. K. (Valen Engineering Ltd., Montreal)  
Preprint. Ottawa, Canadian Nuclear Association, 1962. 26p.

The extremely stringent requirements for leak tightness and material behavior of valves to be used in the primary coolant system of a nuclear power plant are summarized. Tables of recommended types of materials are given. Special design features, fabricating methods, and testing procedures are discussed. (A.G.W.)

- 6.300 TRENDS IN SODIUM EQUIPMENT  
R. W. Dickenson and J. B. Williams (AI)  
Nucleonics 19, No. 1, 65-70 (1961) Jan.

Discussions are given concerning developments in heat exchangers, steam generators, piping and nozzles, valves, and instrumentation.

NSA 15:7099

- 6.300 A Combination Strainer and Blocking Valve for Liquid Metal Systems  
Nayor, F. S. and McDonald, J. S.  
Atomics International, Div. of North American Aviation, Inc.  
Canoga Park, Calif.

NAA-SR-5241, 30 August 1960, 20 p. Contract AT-11-1-GEN-8

A 3-in. pipe-size combination valve and strainer device performed satisfactorily when tested in a sodium system. The device provided a means of removing an in-line strainer element from the system without draining the sodium and alternately served as a plug type blocking valve. Tests were conducted over a temperature range of 500 to 950 F and system pressures of 0.5, and 10 psi at NaO contents of 50 to 400 ppm. The strainer element was isolated from the system by freezing the sodium around the valve plug. The time required to freeze the sodium was found to be primarily a function of system temperature, a typical value being 75 min for a system temperature of 800 F.

NSA 14:22970

- 6.300 Valve Stem Freeze Seal for High-Temperature Sodium  
McDonald, J. S.  
Atomic International, Div. of North American Aviation, Inc.  
Canoga Park, Calif.  
NAA-SR-4869 July 30, 1960, 37 p. Contract AT-11-1-GEN-8

Valve stem freeze seals for high-temperature service in advanced sodium-cooled reactor systems were studied. An experimental model, suitable for use with a 6-in. size valve, operated satisfactorily under a variety of conditions. The freeze seal region was cooled by natural convection to ambient atmosphere; cooling by both circumferential and longitudinal finned sections was experimentally studied. The operating conditions included sodium bulk temperatures up to 1300 F, sodium pressures up to 75 psig, and ambient temperatures as high as 150 F. Anti-convection rings were positioned in the sodium-filled annular between stem and stemguide, and the effects of their presence was studied. Predictions of temperature profiles along the stem, using several different analytical methods, were compared with experimental results.

NSA 14:21079

- 6.300 Thermal Cycling and Leakage Tests of 12-inch Sodium Valves  
Baroczy, C. J.  
Atomics International, Div. of North American Aviation, Inc.,  
Canoga Park, Calif.  
NAA-SR-3961, Sept. 23, 1959, 30p.

Tests of 12-in. sodium valves for use in the Hallam nuclear power facility are described. The valves were thermally cycled at 680 to 1100 F in a sodium loop and periodically examined for across-the-seat leakage. Results are tabulated. A discussion of testing procedure and recommendations is included.

NSA 14:19057

- 6.300 Lawrence, A. C. et al. (to Foster Wheeler Ltd.)  
Heat Exchange System  
Brit. 788,751. January 8, 1958

A permanently packed valve housing suitable for use in heat-exchange systems containing liquid Na, a Na-K alloy, or other liquid exchange medium is described.

CA 52:14247

- 6.300 KAPL-M-JMG-7 Knolls Atomic Power Lab., Schenectady, N. Y.  
Examination of S1G Sodium Stop Valve Bellows. Gerken, J. M.  
Jan. 4, 1957. 9p. Contract W-31-109-Eng-52

Two 8-inch Na stop valve bellows were endurance tested and an evaluation was made of the bellows welds. Mass spectrometer leak testing of these bellows indicated that they were leak tight. A 2-inch Na stop valve bellows which leaked at a point on one of the outer welds was examined for the cause of leaking. The weld in the region of the leak was found to be severely oxidized internally, indicating that the flow of inert shielding gas failed momentarily during welding.

NSA 11-3554

- 6.300 Two Inch Stop Valve Tests with Sodium  
Kennedy, G. E. and E. C. King  
Mine Safety Appliances Company, Callery, Penna.  
Contract NObs-65426. Memo Report 107. March 5, 1956

The integrity of the bellows of the 2 inch stop valve on the S2G drain system was determined during freezing and thawing of sodium following a dump operation into the hold tanks. The valve was so positioned that a minimum of sodium should be held up in it. The test was run three times to determine whether subsequent freezing and thawing of the residual sodium would cause failure of the bellows. The valve performed satisfactorily.

- 6.300 NP - 5921  
PROGRESS REPORT NO. 33 FOR FEBRUARY AND MARCH 1956. W. J. Posey, ed.  
Apr. 9, 1956. 57p. Contract NObs-65426

Progress is reported on the tests made on models of the S2G steam generators. Modifications of a 1000 KW test unit were made to permit adequate testing of the 3000 KW generators. The cyclic test program for the S2G is outlined. Typical Na flow data are given for the cyclic testing of the S2G evaporator. The operational history of this evaporator is also discussed. Progress is also reported on research pertaining to liquid metal system components, including fundamental heat transfer studies and component development and testing. Diagrams are given of the steam generators and tube joints. Operating characteristics of the liquid metal system are tabulated. The ability of transition welds to withstand the rapid temperature changes anticipated during scram conditions was studied. The suitability of stainless steel bellows for use in 8-in. S2G sodium valves was also studied. Results are given of 14 runs to determine the minimum velocity necessary to remove entrained gas by forcing it downward through the 5½-ft vertical leg for separation in the lower expansion tank. The nitriding of metals in Na is also discussed. The weight losses of Be specimens in 900°F Na are shown. A study was made of the characteristics of water-NaK leaks and applicable sealing methods. Data are given on the corrosion rate of Cr-Mo steel samples in NaK. It was found that the solubility of O in NaK is dependent on K concentration.

- 6.300 KAPL-M-EDL-124  
S2G Valve Sodium Freeze Seal Evaluation. Phase II.  
P. K. Salzman and F. N. Schell. Nov. 20, 1956. 50p.

The design of the S2G 8-inch sodium stop valve freeze seal was evaluated under established conditions by cycling before and after a simulated bellows failure. The effectiveness of the freeze seal under severe ambient, water flow and insulation conditions was also evaluated. The stop valve operated successfully under all test conditions.

- 6.300 NP-6220  
Mine Safety Appliances Company, Callery, Pa.  
Test of Proposed Design SIG Bellows in Sodium  
Memo Report 100 by Kennedy, G. E. and E. C. King.  
Dec. 22, 1955. 7p.  
Contract NObs-65426

Twenty stainless steel bellows of the proposed SIG design have been tested, by cycling through a 3 in. stroke, while immersed in approximately 850°F sodium and under external pressure. Sixteen of these bellows were tested at a cycle rate of 12 per min. The last four bellows were tested with a 4 min. time delay between each half cycle. Under these latter conditions, two bellows made by Breeze Manufacturing Company, were cycled without failure in excess of 87,000 times. All the other bellows failed by leaking except one in which the stem bound.

NSA 11:4920

- 6.300 NP-5689  
TEST OF A PISTON OPERATED VALVE FOR SODIUM SERVICE. R. A. Tidball  
and T. A. Ciarlariello. June 9, 1955. 28p.

An 8-in. piston operated split gate valve, fabricated by the Chapman Valve Mfg. Co. for water service, was remodeled for sodium service and tested by exposure to 850°F sodium for 1152 hours during 4520 operating cycles. Seat leakages varied but were always below 0.4 cu ft/hr. Disassembly by the manufacturer showed no damage other than a blackening of the Malcolmized surfaces, but with no loss in hardness, and a slight deformation on the back of the gates. These tests showed that piston operated valves are suitable for sodium service. Changes are recommended to reduce the seat leakage and pumping power required for operation.

- 6.400 APAE-112-Vol. III  
30 MEGAWATT HEAT EXCHANGER AND STEAM GENERATOR FOR SODIUM COOLED  
REACTOR SYSTEM. VOLUME III. MATERIAL AND WELDING SPECIFICATIONS  
 (Alco Products, Inc. Schenectady, N. Y.)  
 June 29, 1962. Contract AT(11-1)-666. 58p.

Material inspection and welding specifications are presented for various parts of both the intermediate heat exchanger and steam generator. Tables are included that indicate the applicable parts and assemblies to which these specifications apply. For other parts, where the material requirements are not severe, the ASTM or other indicated specifications are applicable.

- 6.400 APAE-112-Vol. IV  
30 MEGAWATT HEAT EXCHANGER AND STEAM GENERATOR FOR SODIUM COOLED  
REACTOR SYSTEM. VOLUME IV. OPERATION AND MAINTENANCE PROCEDURES  
 (Alco Products, Inc. Schenectady, N. Y.)  
 May 15, 1962. Contract AT(11-1)-666. 65p.

The design, characteristics, shipping and installation procedures, operation procedures, scram and casualty conditions, leak detection, maintenance, water chemistry recommendations, and sodium purity control recommendations for the intermediate heat exchanger and steam generator for 30-Mw sodium cooler reactor systems are described and discussed. (N.W.R.)

- 6.400 "Heat Transfer in NaK Alloy," R. A. Baker and A. Sesonske,  
 Nuc. Sci. Eng. 13(1962), p 283-8. - A NaK heat transfer loop was designed to minimize experimental errors and yield results with a high degree of reproducibility. Air heat transfer coefficients were determined for both tube and annulus in a horizontal concentric tube NaK (56% K) to NaK exchanger.

NSA 16:25535  
 CA 57:13580g

- 6.400 LIQUID METAL HEAT TRANSFER IN NUCLEAR POWER REACTORS  
 Friedland, Aaron (Atomic Power Development Associates, Inc. Detroit) Preprint Paper No. 90. New York, Engineers Joint Council, 1962, 26 p.

The status of liquid metal heat transfer studies is briefly reviewed. The sodium cooled Enrico Fermi Fast Breeder Reactor is described, with emphasis on the aspects of design and operation relating to heat transfer. (46 references) (auth)

- 6.400 CNEN Program For a Mercury Binary Cycle Nuclear  
Power Plant. Aldo Forcella ( CNEN, Italy) Preprint Paper No. 14.  
 NY Engineers Joint Council 1962 18p.

A program leading to construction of a prototype plant consisting of a Na-cooled fast reactor system in which the heat generated in the primary Na is used to raise the Hg vapor in a Na-Hg boiler is described. This vapor is then expanded in a turbo-generator set where part of reactor heat is converted to electricity. The exhaust Hg steam flows thru a condensor-H<sub>2</sub>O boiler where remaining heat energy is utilized to generate water steam which is then fed to another turbo generator thru a conventional steam cycle. Discussions of Hg plant equipment thermodynamics and economic considerations are included.

NSA 16:31303



6.400 DEVELOPMENT OF A LIQUID METAL HEAT TRANSFER FACILITY FOR UNIVERSITY USE

F. G. Hammett, University of Mich., Ann Arbor, Mich.  
Trans. Am. Nuclear Soc. 5: No. 1261-2 June 1962

NSA 16:24651

6.400 NP-11354  
MERCURY CONDENSING RESEARCH AND DEVELOPMENT EFFORT CONDUCTED AT TAPCO.

This report is the result of the NASA request for an interchange of information between AEC, NASA, and WADD contractors on the topic of mercury condensing. Included are the following:

- (1) Laboratory bench experiments to define problem areas, to determine design criteria for operation in a space environment, to obtain basic design data and to develop mathematical models describing the hydrodynamics of condensing mercury;
- (2) design and tests of experimental condensers;
- (3) design, test, and delivery of prototype condenser-radiators;
- (4) zero gravity testing of condenser design concepts in C131B and KC 135 aircraft. (AGN Lib. 2-3572)

6.400 Average and Local Heat Transfer for Crossflow of Liquid Hg in a Tube Bank, C. L. Rickard (Cornell Univ., Ithaca, N. Y.)  
Dissertation Abs. 22:2742 (Feb 1962)

Local and heat transfer coefficients were obtained for the flow of mercury normal to a staggered bank of tube . . . Results are presented showing the effects of Reynolds No., Prandtl No. wetting of the tube surfaces by the Hg, gas entrained in the liquid metal flow . . .; gas entrained in the liquid metal flow reduces heat transfer coefficients only under condition of non-wetting and wetting or non-wetting of the heat transfer surfaces has no effect on the coefficients in the absence of gas entrainment and surface fouling; friction factors measured for the flow of mercury through the tube bank under non-wetting conditions are in general agreement with those of ordinary fluids and wetting or non-wetting of the tubes surfaces in a tube bank has little or if any effect on the pressure loss . . . for heat and momentum. For practical calcn. of film coefficient of heat transfer, an interpolation formula is proposed.

NSA 16:22310

6.400 WORKING FLUIDS FOR HIGH TEMPERATURE, RANKINE CYCLE, SPACE POWER PLANTS. D. L. Cochran, Aerojet-General Nucleonics, San Ramon, California. Presented at the National Aeronautic and Space Engineering and Manufacturing Meeting (1961)

An analysis is presented of the relative suitability of sodium, potassium, rubidium, and cesium as working fluids in a high temperature, Rankine cycle, space power plant. Turbine inlet temperatures of from 1800 to 2000°F with corresponding condensing temperatures of from 1240 to 1530°F are considered. The criteria by which the fluids are evaluated are the thermodynamic cycle characteristics, heat transfer and fluid friction characteristics, metallurgical compatibility, and the influence of the fluids on the design of the turbine, bearings, radiator, generator, and pump. The turbogenerator unit is thought to be the most critical component and it is found that the working fluid will determine the required number of turbine stages and will therefore establish the turbogenerator bearing arrangement. It is not known whether blade erosion will be a problem. However, since mercury and steam turbines have experienced blade erosion and since potassium has the lowest tendency to cause erosion, potassium appears to be the best over-all working fluid. If blade erosion is found to be of no consequence, then rubidium may result in fewer problems and greater reliability in the turbogenerator unit, and on this basis rubidium would then be the best choice of working fluid.

- 6.400 BNL-756  
DEVELOPMENT OF SNAP-2 HEAT TRANSFER COMPONENTS  
W. D. Leonard and R. D. Keen, Atomics International, Second Annual High Temperature Liquid Metal Heat Transfer Technology Meeting, May 17-18, 1962

Description of SNAP-2 system and its major components, in both the NaK and Mercury Loops. The progress and revisions of the developmental components is described.

- 6.400 BNL-756  
DESIGN AND FABRICATION OF A 2100°F FORCED CONVECTION LI TEST LOOP (Cb-1Zr)  
Ivan L. Gray, Martin Marietta Corp., Nuclear Div., Second Annual High Temperature Liquid Metals Heat Transfer Technology Meeting, May 17-18, 1962

A progress report on the design, fabrication, and installation of a one-inch diameter Cb-1Zr loop using EM pump flow to attain 20 gpm with lithium. The general design and arrangement are described as well as component development. The system operates within a vacuum chamber, 7 ft dia. by 19 ft long. Field welding of one inch Cb-1Zr tubing by means of a rotating fixture which was purged with purified argon. Good quality, defect free welds were reported.

- 6.400 NASA TN D-1188  
SNAP-8 RADIATOR DEVELOPMENT. Presented at the Government-Industry Conference on Mercury Condensing. April 18, 1961, J. R. Payne, Aerojet-General Nucleonics

The SNAP-8 system is at least one order of magnitude larger than the other two mercury rankine cycle plants being developed today. This larger size creates some radiator design problems that require a different approach from that being used on SNAP-2 or Sunflower. The design format is presented.

- 6.400 "Turbulent Heat Trans in Liq Metal - Fully Developed Pipe Flow with Constant Wall Temp," N. Z. Azer & B. T. Chao. Intern J. Of Heat Mass Transfer 377-83 (1961)

Nu and temp profile for low Pr fluids of const prop. flowing in a smooth pipe with const. wall temp. were eval. Use is made of the theoretical expression for ratio of eddy diffusivities.

CA 56:290e

- 6.400 IS-273, A Condenser for the Vacuum Distillation of Metals, Burnet, G., Buchanan, W., (February 1961)

A condenser suitable for use in the distillation of metals was designed. The temperature of the condensing surface was established by controlling the pressure over boiling NaK-78 contained within the condenser. Performance was evaluated in test units in which pure bismuth was distilled as the test metal.

- 6.400 Analyt. Study of Heat Trans. Rates For Parallel Flow of Liq. Metals thru Tube Bundles II, A. J. Friedland and C. F. Bonilla (BNL) AIChE Journ. 7, 107-12 (1961)

Describes a theoretical analysis of heat trans to liq metals in parallel flow through tube bundle.

CA 56:9908i

6.400 AD 259606  
Heat Exchange During the Flow of Liquid Metal in the Laminar and Transition Regions  
Petukhov, B. S. and Yushin, A. Ya.  
Aerospace Technical Intelligence Center, Wright-Patterson Air Force Base, Ohio  
Trans. No. MCL-993 of Doklady Akademii Nauk SSSR 136:pp. 1321, 1961  
26 May 61, 9 p. incl. illus.

An experimental investigation was conducted of the heat transfer occurring during forced flow of Hg in a circular pipe in the laminar and transition regions with constant density of the heat flux on the wall. The heat transfer was studied under conditions of Hydrodynamic and thermal stabilization of the flux. The following conclusions were drawn: (1) due to the presence of grooves in the working sections of the apparatus a pronounced unevenness occurred in the distribution of the density of the heat flux per unit length of the pipe over the length of the section; and (2) the values of the Nusselt (Nu) number obtained in the literature are understated by comparison, and Nu depends on the Peclet number (Pe), in the laminar region. NSA 15:15729  
CA 56:11390e

6.400 NAA-SR-MEMO-6798  
A MODULAR, LOW-COST, SODIUM-HEATER STEAM GENERATOR  
(Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.) Oct. 23, 1961. Contract AT(11-1)-Gen-8. 16p.

A proposed design and development program for a potentially economical, high-performance, sodium-heater steam generator is described. The concept employs modular units grouped together to provide for any combined power level desired. Fabrication expense is shown to be reduced by the reduction in heat transfer area requirements. This reduction is achieved through improved heat transfer coefficients which exist under supercritical steam conditions. The testing of two small units (~18 Mw total) is shown to be sufficient to verify performance for any size unit because of the modular concept employed. (auth)

6.400 CA 56-3301i  
"Design of Reliable and Economic Heat Exchanger for High Temperature Na Service," R. D. Seifert and L. E. Phillips. American Soc. Mech. Engr. Paper No. 61-SA-41 (11p) 1961

A report is presented on problems encountered in design optimization of an intermediate Na-Na heat exchanger and steam generator for a nuclear power plant operating at 1200°F. Na in the intermediate zone. The basic design of the intermediate heat exchanger was a shell-and-tube type exchanger with Type 316 SS for tubes, tube sheets and channels and type 304 SS for other disk and doughnut baffles. Special design problems were outlined. The steam generator design was complicated by the fact that the outside of the tubes must be resistant to high temperature Na while the tube interiors (steam side) must be resistant to stress-corrosion cracking in the presence of chlorides and dil. NaOH. Na and steam or H<sub>2</sub>O will be separated only by the clad tube wall, with no intermediate space. Possible hazards are evaluated and not believed serious ....Type 316 SS tubes, internally clad with Inconel were selected both for boiler and superheater. Special welding methods are under development. Units of 30 megawatt size of both the intermediate H.T. exchanger and steam generator will be built.

6.400 AEC Sodium Components Development Program (NASA-AEC Liquid Metal Corrosion Meeting, Dec. 1961 at BNL)

A survey of past, present, and future with listed references  
TID-7626 (Part 1) (AGN Lib. 2-2786)

- 6.400 LAMS-2541, 2000 Kilowatt Sodium Test Facility, Whinery, L. A.,  
(March 1961)

The design and construction work completed on the 2000 KW sodium test facility during the period from April 1958 to Oct 1959 is described. The purpose of the facility project is to test models of equipment components which are to be used in a molten plutonium, sodium-cooled fast reactor.

- 6.400 LAMS-2531  
QUARTERLY STATUS REPORT ON LAMPRE PROGRAM FOR PERIOD ENDING  
FEBRUARY 20, 1961. Anon Contract W-7405-eng-36. 26 p.

The LAMPRE-I project is summarized in terms of capsule development and production, sodium system, cover gas system, capsule charge, shielding, and fuel storage facility. The loading of the LAMPRE-I core was begun on January 20, 1961 with the sodium temperature set at 160°C. The reactor was brought to criticality on February 17, 1961. Operation of the Sodium Test Facility was continuous except for 6 maintenance and inspection shutdowns resulting in 680 idle hours. The intermediate sodium heat exchanger, steam generating unit, centrifugal sodium pumps, sodium flow control valves, and gas-fired sodium heater are discussed. Heat transfer test results are given for the various components. Research and development activities for the LAMPRE program are reported in the topics fuel and alloy program, container alloy development, direct contact core studies, development of liquid fuels, container materials for reactor fuels, and fuel reprocessing.

- 6.400 IMPROVEMENTS IN OR RELATING TO HEAT INSULATION DEVICES  
Everett Long (To United Kingdom Atomic Energy Authority)  
British Patent 846,753. August 31, 1960.

The problem: hot and cold sodium are kept in header tanks on top of the reactor core and separated from each other by a diaphragm (more on abstract).

NSA 14:24230

- 6.400 APAE-66  
SCALE "UP OR DOWN" ANALYSIS FOR PROTOTYPE TEST  
Alco Products, Inc., Schenectady, N. Y. May 1, 1960. 74 p.  
Contract AT(11-1)-666. OTS.

... Na heat exchanger and Na steam generator.

NSA 14:24215

- 6.400 Improvements in or Relating to Heat Exchangers  
Long, Everett and Symes, R. J.  
British Patent 846, 754, August 31, 1960  
NSA 14:24243

A heat exchanger of the shell and tube type was invented for heat exchange between primary liquid sodium and secondary liquid sodium. The heat exchanger unit is removable and free to move axially to allow for thermal expansion.

- 6.400 INTERMEDIATE HEAT EXCHANGER AND STEAM GENERATOR FINAL DESIGN.  
THERMAL AND MECHANICAL DESIGN  
(APAE-78(Vol. I))  
(Alco Products, Inc., Schenectedy, N.Y.) Sept. 30, 1960. 382 p.  
Contract AT(11-1)-666.

The final designs are given for a Na-to-Na intermediate heat exchanger and a Na-to-water steam generator. (More on abstract.)

NSA 15: 11118

- 6.400 INTERMEDIATE HEAT EXCHANGER AND STEAM GENERATOR FINAL DESIGN.  
CHEMICAL AND STRESS ANALYSIS  
(APAE-78(Vol. II))  
(Alco Products, Inc., Schenectedy, N.Y.) Sept. 30, 1960, 450 p.  
Contract AT(11-1)-666

Chemical and stress analyses were made of a Na-to-Na intermediate heat exchanger and a Na-to-water steam generator as an extension and modification to previous analyses. (More on abstract.)

NSA 15: 11119

- 6.400 INTERMEDIATE HEAT EXCHANGER AND STEAM GENERATOR FINAL DESIGN  
SPECIFICATIONS  
(Alco Products, Inc., Schenectedy, N.Y.) Sept. 30, 1960, 90 p.  
Contract AT(11-1)-666 (APAE-78(Vol. III))

Twenty-three material, inspection, and welding specifications are presented for the various parts of the intermediate heat exchanger and steam generator.

NSA 15: 11120

- 6.400 TECHNICAL DESCRIPTION OF A SODIUM-COMPONENT TEST INSTALLATION  
(NAA-SR-Memo-4754. Atomics International. Div. of North American Aviation, Inc., Canoga Park, Calif.) May 2, 1960. 87 p.

A Sodium-Component Test Installation designed primarily for operational testing of sodium-heated steam generators and heat exchangers suitable as prototype components for large, sodium-cooled power plants is described. The installation consists of a 35-Mwt gas-fired sodium heat source, a main primary-sodium system, a main secondary sodium system, a water-steam cycle system, and a cooling tower for heat rejection to air. Design of the main piping and auxiliary systems, system operation and objectives, and safety aspects are discussed.

NSA 15: 19490

- 6.400 Flow Patterns of Two-Phase Flow - A Survey of Literature  
Vohr, John H. TID-11514 Contract AT(30-3)-187. 59p. Dec. 15, 1960.  
(CU-2-60-AEC-187-Ch.E)

A survey was made of the literature on flow patterns occurring in simultaneous gas-liquid flows through ducts. Descriptions of gas-liquid flow patterns and the terminology used in denoting them are presented. The experimental investigations from which the descriptions are taken are surveyed. The relations between flow pattern and pressure drop in gas-liquid flows are discussed. Horizontal, vertical, and vertical boiling flows were investigated. NSA 15:18192

- 6.400 MND-P-2309  
MERCURY BOILER DEVELOPMENT REPORT FOR SNAP I  
J. Jicha and J. Keenan. The Martin Co., June 1960.  
Contract No. AT(30-3)-217.

The mercury-boiler development program was undertaken to develop a system that would utilize the heat of radioisotope decay to boil and super-heat mercury vapor for use with a small turbine-generator package. Through the use of a Rankine cycle, the mercury vapor can be provided continuously to power a turbine-driven alternator and produce electricity for extended periods of time. This mercury boiler and the related power-conversion system was planned for a satellite that would orbit the earth. This system design and development program was designated as SNAP-I. Development of the mercury boiler is described and a chronological description of the various mercury-boiler concepts is presented. The applicable results of an extensive literature survey of mercury are included. The mercury-boiler experimental-test-program description provides complete coverage of each experimental boiler and its relation to the system design of that period. A summary of all mercury boilers and their final disposition is also given. NSA 15:13463

- 6.400 ORNL-1330  
HEAT EXCHANGER DESIGN CHARTS  
A. P. Fraas and M. E. LaVerne  
Dec. 7, 1952. Decl. Oct. 9, 1959, 82 p. Contract W-7405-eng-26. OTS.

Several design charts of the ORNL-ANP liquid-to-liquid heat exchanger are given along with brief explanations and sample calculations. Fluid flow and pressure losses are discussed, and the heat transfer coefficients are calculated from physical property data of the fluids.

NSA 14:1608

- 6.400 CF-56-7-135  
EXAMINATION OF ORNL 1 AND 2 INTERMEDIATE HEAT EXCHANGERS, TYPE 1HE-3  
J. H. DeVan and R. S. Crouse  
July 20, 1956, Decl. Oct. 9, 1959, 17 p. OTS.

... failure, due to NaK leak.

NSA 14:2538

- 6.400 MND-P-2381  
SNAP I POWER CONVERSION SYSTEM CONDENSER-RADIATOR DEVELOPMENT  
Period Covered: February 1, 1957 to April 15, 1959, TAPCO  
(ER-4056) R. J. Kiraly and D. C. Reemsnyder. June 1960

Although no prototype hardware was designed or tested in the program, the concept of rejecting waste by radiation in a gravitationless environment was proved feasible. NSA 14:26040

- 6.400 MND-P-2380  
SNAP I POWER CONVERSION SYSTEM CONTROL DEVELOPMENT. Period Covered:  
February 1, 1957 to June 30, 1959. TAPCO (ER-4055)  
W. E. Dauterman, et. al., June 1960.

A description of test and prototype hardware and performance data are included. NSA 14:26039

Combustion Engineering, Inc. Nuclear Components Engineering  
Dept. , Chattanooga,  
SODIUM COMPONENT STUDY. Feb. 1959. 292p. Contract AT(11-1)-665.  
\$45.00(ph), \$11.10(mf)OTS.

A design study is presented of a heat exchanger system to produce superheated steam from a source of heated radioactive Na. The purpose of the study was to produce a conceptual design of a less expensive and more reliable heat exchanger and steam generator of advanced design and improved performance for use in sodium-cooled reactor systems. The study was based on a 70-Mwh steam generator and a 70 Mw heat exchanger. Superheated steam at 1050°F and 2300 psig will be produced from 600°F feedwater. The heat source will be radioactive Na cooled from 1200 to 700-900°F. (T.R.H.)

- 6.400 Heat Exchange of a Plate in a Turbulent Boundary Layer of Incompressible Liquid at  $Pr \ll 1$ . E. D. Fedorovich (Polzunor Leningrad Central Turbine Construction Inst.).  
Inzhener. - Fiz. Zhur., Akad. Nauk Belorus.  
S.S.R. 2, No. 9, 3-11 (1959) Sept. (in Russian)

Results are presented of a theoretical and experimental investigation of heat exchange of a plate in liquid flow where the Prandtl number is much less than 1 (liquid metal). Measurements of the coefficient of heat transfer of a plate in a molten sodium flow was in satisfactory agreement with this calculation.

NSA 14:4421

- 6.400 AD 256511  
PROGRESS REPORT NO. 36 FOR AUGUST AND SEPTEMBER, 1956  
Posey, W. J. (Ed.)  
Mine Safety App. Co., Callery, Penn. NP-6132, 70 p. (Oct. 10, 1956)

Tests are continuing on the 3000 KW steam generator. The unit has been subjected to a life test at cyclic conditions. The test system is shown schematically. The cycle test has been completed on the evaporator for the 3000 KW steam generator. A complete operational history of the evaporator is given. Stress tests are continuing on a tee in the S2G system used to join to liquid metal streams of different temperatures. The work on nitriding of Be, 347 stainless steel and tool steel is complete; tables of corrosion rates of the three metals in liquid Na are presented. Methods of installing freeze seals and design of the seals are being investigated to prevent Na from being carried in the venting system of the S2G into the upper level reactor compartment. Radioactive lead experiments were continued.

- 6.400 AD 256511  
PROGRESS REPORT NO. 37 FOR OCTOBER AND NOVEMBER 1956  
Posey, W. J. (Ed.)  
(Mine Safety Appliances Co., Callery, Penn.) NP-6179, 60 p.  
(Dec. 13, 1956)

The operation of the 1000-kw heat transfer unit at high temperatures was demonstrated to aid development of components for such service and to add to the body of liquid metal technology, 3000-kw steam generator tests were made as part of a steam generator development. Research on liquid metal system components is reported. Thermal shock tests were made on a tee in the S2G system used to join two liquid metal streams of different temperatures. Experimentation in which results are evaluated by chemical or radiochemical techniques including experiments in the field of organics is reviewed. High velocity corrosion testing in biphenyl of reactor materials is reported.

- 6.400 TID 3544  
EFFECT OF SPACER DENSITY ON HEAT TRANSFER AND PRESSURE DROP IN THE ART FUEL-TO-NAK HEAT EXCHANGER. J. K. Wantland. Oct. 10, 1956. Decl.  
Sept. 15, 1959. 10p. (CF-56-10-39) \$1.80(ph), \$1.80(mf) OTS.  
NSA 13:21428.

6.400

TID 3305

HEAT TRANSFER APPLICATION OF LIQUID LITHIUM, LIQUID METALS AND LIQUID METAL PUMPS. Frederick E. Frost and Glen Maynard. Oct. 26, 1956. 15p. (M-6286)

This bibliography contains 126 references arranged under the following headings: Liquid Lithium, Liquid Metals, Liquid Metal Pumps, and General.

6.400

ORNL-2012 (Pts. I, II, III, Del.)

AIRCRAFT NUCLEAR PROPULSION PROJECT QUARTERLY PROGRESS REPORT FOR PERIOD ENDING DECEMBER 10, 1955

A. W. Savolainen, ed. March 11, 1956 Decl. with deletions Oct. 22, 1959, 206 p. Contract W-7405-eng-26. OTS.

Includes ART Na pump, a pump for NaK to 1400°F, NaK heat exchangers, and NaK radiators.

NSA 14:6042

6.400

NP - 5921

Progress Report No. 33 For February and March 1956. W. J. Posey, ed. Apr. 9, 1956. 57p. Contract NObs-65426

Progress is reported on the tests made on models of the S2G steam generators. Modifications of a 1000 KW test unit were made to permit adequate testing of the 3000 KW generators. The cyclic test program for the S2G is outlined. Typical Na flow data are given for the cyclic testing of the S2G evaporator. The operational history of this evaporator is also discussed. Progress is also reported on research pertaining to liquid metal system components, including fundamental heat transfer studies and component development and testing. Diagrams are given of the steam generators and tube joints. Operating characteristics of the liquid metal system are tabulated. The ability of transition welds to withstand the rapid temperature changes anticipated during scram conditions was studied. The suitability of stainless steel bellows for use in 8-in. S2G sodium valves was also studied. Results are given of 14 runs to determine the minimum velocity necessary to remove entrained gas by forcing it downward through the 5½-ft vertical leg for separation in the lower expansion tank. The nitriding of metals in Na is also discussed. The weight losses of Be specimens in 900°F Na are shown. A study was made of the characteristics of water-NaK leaks and applicable sealing methods. Data are given on the corrosion rate of Cr-Mo steel samples in NaK. It was found that the solubility of O in NaK is dependent on K concentration.

6.400

PRELIMINARY DESIGN OF ANNULAR TUBE HEAT EXCHANGERS FOR CIRCULATING FUEL SYSTEMS

C. L. W. Berglin. Feb. 1957, 9 p. (AAEC/E-4). Atomic Energy Commission Research Establishment, Cucas Heights, New Smith Wales, Australia.

A suggestion appearing in AAEC/E-2 is developed, and it is shown that the annular heat exchanger for circulating fuel systems is practical.

NSA 13:12251

6.400

Heat Transfer Rates to Crossflowing Mercury in a Staggered Tube Bank by Hoe, I. R. J. and O. E. Dwyer (Brookhaven National Lab., Upton, N. Y.) and D. Dropkin (Cornell Univ., Ithaca, N. Y.) Trans. Am. Soc. Mech. Eng. 79, 899-907 (1957) May.

An experimental heat-transfer program has been under way for some time at the Brookhaven National Laboratory, the general purpose of which is to obtain and correlate heat-transfer coefficients for liquid metals flowing outside of tube banks. This paper covers one phase of the program; i.e., the measurement of heat-transfer coefficients for mercury flow normal to a staggered tube bank. The factors studied were linear velocity, tube location in the bank, circumferential variation of the local coefficient for a single tube, type of contact, i.e., wetting versus nonwetting, and pressure drop.

NSA 11:6709



OPERATING EXPERIENCE AND RESULTS OF TESTING THE FIRST APDP PROTOTYPE LIQUID METAL ONCE-THROUGH STEAM GENERATOR

Jones, R. H., Lempges, T. E., Williams, H. J., and Wooten, J.  
(Atomic Power Development Ass. Inc., Detroit, Mich) AECU-3700,  
67 p. (Dec 1957)

To aid in the development of a once-through steam generator to be used in a sodium-cooled nuclear reactor plant, a small-scale prototype model of the contemplated steam generator was fabricated and subjected to various testing programs. The prototype once-through steam generator, which consists of 7 full-length, 1/2 in. O.D. x 0.050 in. wall, single-wall tubes, was tested for a period of about 1 year to determine its steady-state characteristics and its transient behavior. One year of operation of the unit indicates the once-through steam generator to be entirely satisfactory. It has been subjected to, and successfully withstood, cycling conditions equivalent to a number of years of normal operations. It is interesting to note that, of the 25 unscheduled shut-downs that occurred during the year, none were the result of failure of liquid metal components of the once-through generator. The single-wall tube design was found to be entirely satisfactory.

RECENT DEVELOPMENTS ON THE STANDBY COOLANT SYSTEM FOR THE WEST

MILTON REACTOR, John E. Zerbe, June 20, 1949. Decl. Mar. 27, 1957.  
12p.

The work done previously on the Standby Coolant System was reviewed in the light of more recent reactor designs and heat transfer data. It has been found that if a NaK-Na heat exchanger consisting of 16-1 1/2" OD 60 mil wall stainless steel tubes is used, the thermal stress is reduced to approximately 22,000 psi when 2 1/2% of 30 Mw is transferred under steady state conditions. Further calculations based on dissipating 2 1/2% of 30 Mw have shown that the thermal stress is not influenced noticeably by the temperature rise in the NaK system. This is for both 80-20 (eutectic) NaK and 50-50 NaK. However, assuming the NaK-air exchanger is placed at a height of 55 feet the factor of safety for the various temperature rises in the NaK loops is different. Thus, for 80-20 NaK, if  $\Delta T_{NaK}$  equals 200° F, calculations show that the exchanger must be at least 40 feet in the stack; for  $\Delta T_{NaK} = 150^\circ$  the exchanger must be located at about 86 feet. If 50-50 NaK were used, the factor of safety would be greater than with 80-20 NaK.

SDR PROJECT QUARTERLY TECHNICAL PROGRESS REPORT FOR THE PERIOD MAY 1, 1957 THROUGH JULY 31, 1957. Sept. 30, 1957. 54p.

Engineering studies were made and experimental work was carried out with the objective of demonstrating the feasibility of separation of Na and D<sub>2</sub>O in the SDR reactor. For the engineering studies, a through-tube reactor design was selected. Layouts of fuel-coolant tube and header arrangements were made with a view toward minimizing the probability of mechanical failures of these Na system components. Preliminary studies on Na and D<sub>2</sub>O system requirements and on the design of the D<sub>2</sub>O moderator tank or calandria were started. A survey was made of possible barrier materials, i.e., materials which may be located between the fuel-coolant tubes and the calandria tubes to minimize the consequences of single or multiple-tube failures. Mechanical arrangements for mounting and supporting barrier materials and for detecting leaks were investigated. Conceptual designs of equipment for testing the mechanical integrity of fuel-coolant tube and header joints were completed. Major components of a single-failure rig, in which barrier materials can be subjected to Na streams that simulate Na system failures, were designed, constructed, and assembled. Preliminary design of a multiple-failure test apparatus, in which the effects of both Na and D<sub>2</sub>O failures will be investigated, has been completed. Preliminary design of a mockup test apparatus has been finished; this apparatus, which will be a full scale representation of a section of the reactor, will be used to demonstrate the reliability of integrated Na and H<sub>2</sub>O circulating systems under simulated normal and aggravated reactor operating conditions. The shielding problems associated with radiation limitations on access to header rooms for repairs and maintenance were evaluated. Temperatures, pressures, and flow rates for the secondary Na and steam systems were established.

- 6.400 ANL - 5719  
EXPERIMENTAL BREEDER REACTOR II (EBR-II); HAZARD SUMMARY REPORT.  
L. J. Koch, H. O. Monson, D. Okrent, M. Levenson, W. R. Simmons,  
J. R. Humphreys, J. Haugsnes, V. C. Jankus, and W. B. Loewenstein.  
May 1957. 401p.

The EBR-II consists of an enriched core surrounded by a fertile blanket of depleted U. The fuel pins fit loosely in a thin walled tube filled with static Na for a heat transfer bond. Heat is removed by the primary Na flowing along the outside of the fuel tube. The fuel element lends itself to remote control fabrication methods. Effort was made to achieve a rigid, close-packed arrangement of the fuel and to produce preferential bowing such as to effect a probable bowing coefficient which is essentially zero or negative. Reactor control is effected by movement of fuel into and out of the reactor core. Heat is removed by the primary Na coolant system and transferred to the secondary Na system in a shell-and-tube heat exchanger. The reactor and entire primary system, including heat exchanger, are contained in a large vessel (primary tank) and operate completely submerged in coolant. The large volume of Na in the primary system provides a reliable source of constant temperature coolant. Shutdown cooling is accomplished by natural convection. This bulk volume of Na is also used as coolant during reactor unloading. The reactor, primary coolant system, and all associated equipment are contained in a building in the form of a gastight cylindrical steel sheet (with a normal safety factor of approximately four). Two potential sources of accidental energy release are treated separately.

- 6.400 AD 256511  
PROGRESS REPORT NO. 38 FOR DECEMBER 1956 AND JANUARY 1957  
Posey, W. J. (Ed.)  
(Mine Safety Appl. Co., Callery, Penn.) NP-6209, 42p, (Feb. 13, 1957)

Tests are continuing on the 1000 and 3000 KW steam generators. Two tests were performed with B & W miniature boilers, and results are presented. Corrosion testing of reactor cladding and structural materials in biphenyl at 800°F and 300 psig has been completed. High velocity corrosion testing in isopropyl biphenyl has been completed. The solubilities at high temperatures and pressures of the gases, A, air, CH<sub>4</sub>, N<sub>2</sub> and H<sub>2</sub> in organic moderator coolants are presented.

- 6.400 TID 3544  
SODIUM-WATER-STEAM HEAT EXCHANGERS USE OF STATIC INTERMEDIATE FLUIDS AND THE DETECTION OF LEAKS. J. F. Pearson. June 1957. 13p. (IGR-TN/R-561).

- 6.400 TID 3544  
MINIATURE BOILER TEST-NAK INJECTION (NO. 2). Memo Report 125.  
W. Milich, G. E. Kennedy, E. A. Schultz, and E. C. King.  
Feb. 8, 1957. 10p. (NP-7431) NSA 13:13227

- 6.400 SODIUM AND SODIUM-POTASSIUM ALLOY FOR REACTOR COOLING AND STEAM GENERATION. T. Trocki, W. H. Bruggeman, F. E. Crever. June 30, 1955. 23p. UN-123

A general study of the use of NaK alloys as heat transfer media in reactor cooling systems, heat transfer and steam generating systems, and two specific experimental heat transfer systems, heat exchangers. Problems encountered in the system components, i.e., heat exchangers, pumps (electromagnetic and physical), valves, and instrumentation are covered. A short discussion of the chemical technology of these alloys with respect to contaminants is included. 24 references. CA52: 18147

- 6.400 PRELIMINARY FEASIBILITY REPORT ON THE KAPL REACTOR. Jan. 12, 1949.  
Dec1. May 13, 1957. 109p. KAPL-116

The proposed reactor is a Na cooled, intermediate energy, power breeder. The various components of the reactor and associated equipment are described in detail.

- 6.400 HEAT TRANSFER AND HYDRAULIC CHARACTERISTICS OF THE SRE FUEL ELEMENT.  
T. T. Shimazaki and W. J. Freede. p.273-96 of REACTOR HEAT TRANSFER  
CONFERENCE OF 1956 HELD AT NEW YORK, NOVEMBER 1-2, 1956. John E.  
Viscardi, comp. November 1957. 635p. (TID-7529(Pt.1)(Bks. 1 & 2)

The Sodium Reactor Experiment (SRE) 7-rod fuel element consists of seven equal-diameter fuel rods arranged in a triangular lattice with six of the rods around the seventh rod. The rods are spaced by means of wire wrapped helically around each of the six peripheral rods. The fuel element is located in a coolant tube, the inside diameter of which is slightly larger than the outside diameter of the fuel element. For adequate cooling of the center fuel rod, a definite amount of mixing of the coolant flowing between rods with the coolant flowing between the coolant tube wall and the peripheral rods is necessary. The degree of coolant mixing was determined experimentally by injecting, at the up-stream end of the fuel element, a chemical solution into the coolant stream (water) flowing between the rods, and measuring, at various distances downstream, the chemical concentration in the coolant flowing between the coolant tube wall and the peripheral rods. The results indicated a sufficient degree of coolant mixing. The results also were in agreement with the flow pattern observed by means of high speed motion pictures of the flow which was made visible by weighted sawdust particles in the water. Friction factor data for flow in the coolant tube containing the fuel element are also presented.

- 6.400 HEAT EXCHANGERS AND STEAM GENERATORS  
R. H. Anderson (APDA) p. 215-28 of Proceedings of the 1957  
Fast Reactor Information Meeting held at Chicago, Ill., Nov. 20-21,  
1957.

For the intermediate heat exchangers the basic overall design considerations for the Fermi Reactor, EBR-II, and LAMPRE-II are discussed.

NSA 13:16599

- 6.400 C. L. Rickard (General Dynamics Corp., San Diego, Cal.) O. E. Dwyer  
(Brookhaven National Lab., Upton. N. Y.) and D. Dropkin (Cornell Univ.  
Ithica, N. Y.)  
Heat-Transfer Rates to Cross-Flowing Mercury in a Staggered Tube  
Bank. II Trans. Am. Soc. Mech. Engrs. 80, 646-52(1958) April

As part of a continuing liquid-metal heat-transfer program at the Brookhaven National Laboratory, both local and tube-average heat-transfer coefficients have been obtained for the flow of mercury normal to a staggered tube bank. The bank consisted of sixty 1/2 in. tubes, six wide and ten deep, arranged in an equilateral-triangular array. The paper presents results showing the effects of flow rate, Prandtl number, wetting, gas entrainment, and tube location on the tube-average coefficients. The angular variation of the local coefficient is not considered here, owing to the fact that the values have not been calculated completely from the original data. The mercury results are compared with a few results obtained with water in the same equipment. The heat-transfer runs cover the Reynolds number range of 20,000 to 200,000, whereas the water runs cover the range 8000 to 20,000. Pressure-drop results for both water and mercury flow through the tube bank are reported also. The mercury coefficients for tubes in the interior of the tube bank are well represented by the equation  $Nu = 4.03 + 0.288(Pe)^{0.67}$

NSA 12:7791

- 6.400 FREE CONVECTION HEAT TRANSFER TO WATER AND MERCURY IN AN ENCLOSED  
CYLINDRICAL TUBE. J. P. Hartnett, W. E. Welsh, Jr., and F. W. Larsen.  
Presented at Nuclear Engr. And Science Conference, Chicago, Mar. 17-21,  
1958. Preprint 27, Session 20. New York, Amer. Inst. of Chem. Engrs.,  
1958. 22p. NSA 12:10550.

- 6.400 TID 3544  
HEAT TRANSFER COEFFICIENTS OBSERVED IN SMALL SODIUM EXCHANGERS.  
Seymour C. Hyman. Chem. Engr. Prog. 54, No. 10, 81-2(1958)Oct.  
NSA 13:1647

6.400     DESCRIPTION OF INTERMEDIATE HEAT EXCHANGER AND STEAM GENERATOR SELECTIONS

Final Report. R. W. Schroeder and M. A. Chionchio. Feb. 25, 1959. Includes Supplement: MECHANICAL DESIGN BASIS FOR HEAT EXCHANGER COMPONENTS FOR NUCLEAR POWER PLANTS. (Griscom-Russell Co., Massillon, Ohio). Oct. 30, 1958. Contract At(11-1)-664. 151 p.

A discussion is given of the development studies of heat exchangers and steam generators for Na-cooled reactor systems. Design specifications are included for offset-tube and U-tube intermediate heat exchangers, and involute-tube and offset-tube steam generators with removable bundles. Estimated costs for 70-Mw designs are included. Recommendations for the proposed development program are described. (B.O.G.)

NSA 15: 19515

6.400     CENC-1038  
           SODIUM COMPONENT STUDY

Combustion Engineering, Inc. Nuclear Components Engineering Dept., Chattanooga, Tenn.

A design study is presented of a heat exchanger system to produce superheated steam from a source of heated, radioactive Na.

6.400     AD259606 Heat Exchange During Flow of Liq Metal in Laminar and Transition Regions (translation)

An investigation was conducted of Heat transfer occurring during forced flow of Hg in circular pipe in laminar and transition regions with constant density of heat flux on the wall .....

6.400     Corrosion Screening of Component Materials for NaK Heat Exchange Systems, Basham, S. J. et al. (BMI)  
Presented at Nuclear Engineering and Science Conf. held at Chicago Mar. 17 to 21, 1958. Preprint 24, Session 23, N. Y. AICE, 1958. 27 p.

Sixty-one materials which might be useful for special components, such as valve-seat inserts, valve plugs, shaft-seal facings, and bearings, in high-temperature NaK flow systems were screened in tilting-furnace corrosion experiments. These include high-temperature alloys, pure metals, cermets, and ceramics. The standard test consisted of confining a specimen to the hot end of a sealed Inconel X capsule partially filled with NaK and exposing the capsule for 110 hr (5000 cycles) in a tilting furnace. The hot end of the capsule was controlled at 1600 F. while the cold end was 2100 F. Post test corrosion evaluations were based on metallographic examinations, and specimen weight-change measurements capsule-wall examinations, and specimen surface-roughness changes. The materials were divided into three classes according to corrosion resistance: Class I (most promising) - attached to a depth of 1 mil or less; Class II (marginal) - attached to a depth of 1 to 4 mils; Class III (unsuitable) attached to a depth greater than 4 mils. NSA 12:10593

QUARTERLY PROGRESS REPORT OCTOBER 1 - DECEMBER 31, 1955. 64p.  
Contract (AT-(30-2)-Gen-16). \$0.40(OTS).

Abstracts of papers submitted for journal publication are included. The operational efficiency of the Cosmotron continued high. Developmental work on accelerator design is reported. Services furnished to off-site users of the BNL reactor, irradiation facilities, and services are summarized. Isotope shipments made during the period are listed. Preliminary results in studies on solid-state radioinduced polymerization of styrene grafted to polyethylene and to teflon are reported. Heat-transfer and pressure-drop characteristics were determined for Hg flowing normal to a bank of staggered tubes.

6.400 CF-3746  
REPORT FOR JULY, 1946--FEBRUARY, 1947; FILE RESEARCH AND DEVELOPMENT  
DIVISION. W. H. Zinn. Feb. 28, 1947. Decl. Dec. 28, 1955. 74p.  
\$12.40(ph OTS); \$4.50(mf OTS).

Section 1. Na-K Pressure Drop through the Fast Pile: A model of a section of the reactor was constructed and pressure drops measured first with water and later with Na-K alloy as the circulating fluid.

Section 2. Heat Transfer Data for Steel Tube Copper Cast Heat Exchanger and Film Coefficients of Coolants: Over-all heat-transfer coefficients and film heat-transfer coefficients were obtained with Na-K as the heating fluid in all cases and with Hg and DC-702 silicone oil, respectively, as the coolant. Runs were made at several velocities of fluids.

Section 14. Convection Loop, CP-4: The design and performance of a thermal convection circuit for air cooling of the fast reactor after shutdown are described. The requirements were the removal of 20 kw of energy, 10 min after shutdown, at a temperature difference across the reactor of 100°C.

6.400 NP-5727  
HEAT TRANSFER AND PRESSURE DROP WITH NaK-56 FLOWING PERPENDICULAR TO  
VERTICAL TUBES. Memo Report No. 87. M.J. McGoff and J. W. Mausteller.  
July 29, 1955. 17p. Contract NObs-65426.

A cross-flow heat exchanger has been tested with liquid metal (NaK-56) as the heat-transfer fluid. The heat exchanger consisted of 25 1/2-in.-OD tubes arranged on a 5/8-in. equilateral triangular pitch; 5 rows longitudinal and 5 rows transverse to flow. Operation was up to 900°F at Reynolds numbers of 3000 to 80,000. Heat-transfer coefficients varied to the 0.8th power of the Reynolds number and were higher than have been reported for Hg or pressurized water. Friction factors agreed with those obtained for the more common fluids.

6.400 NP - 3440  
REPORT II ON THE LIFE TESTS ON "FIGURE OF EIGHT" FLAT PLATE HEAT  
EXCHANGERS (Technical Report No. IX). Robert A. Tidball and Kenneth  
R. Barker. Dec. 1, 1950. Decl. Apr. 21, 1955. 14p.

Two "figure of eight" heat transfer systems have been constructed to measure changes in heat-transfer and flow characteristics due to operation at elevated temperatures using eutectic NaK as the fluid. One system has been operating for one year as a life test, the other twenty weeks to determine the effect of added oxygen. The friction factor has increased 10% in life test and the increased 70% in the contaminated system. This increase was accompanied by a decrease in the flow rate. Over-all heat transfer coefficients seem unaffected by operating time or oxygen contamination. Results indicate that decreased performance can be expected if the contamination is kept within reasonable limits by removing the oxygen from the systems before charging and from the cover gas.

6.400

BNL-2446

REACTOR HEAT TRANSFER INFORMATION MEETING HELD AT BROOKHAVEN NATIONAL  
LABORATORY, OCTOBER 18-19, 1954. Dec. 1955. 195p.  
\$1.00(OTS); Dep.; Ind. Dep.; Dep.(mc).

The following unclassified papers, presented at the Reactor Heat Transfer Information Meeting in October, 1954, are included: Heat Transfer Rates to Cross-Flowing Mercury in a Staggered Tube Bank; Specific Heat of Liquid Metal and Salt Mixtures; The Effect of Gas Entrainment on the Heat Transfer Characteristics of Liquid Mercury; Flow in a Thermal Convection Harp in the Grashof Modulus Range From  $10^4$  to  $10^6$ ; Theoretical and Experimental Investigation of Heat Transfer by Laminar Natural Convection Between Parallel Plates; Remarks on Forced Heat Convection in Cylindrical Channels; Potential and Parabolic Velocity Distributions; High Temperature Liquids; Heat Transfer to Boiling Water Forced Through an Electrically Heated Tube; Boiling Density Studies in Multiple Rectangular Channels; Measurement and Prediction of Density Transients in a Volume-Heated Boiling System; Heat Transfer and Corrosion Tests for a Sodium-Cooled Fast Breeder Reactor; and Free Convection in Narrow Vertical Liquid Metal Annuli.

6.400

NP-5279

EFFECTS OF THERMAL CYCLING AND CHLORIDE CORROSION ON STAINLESS STEEL  
STEAM GENERATORS. R. C. Andrews and E. C. King. July 30, 1954.  
Dec. 18, 1955. 40p. Contract NObs-65426, Technical Report  
No. 28.

Steam at 500 psig was produced in Types 347 and 304 stainless steel generators using a NaK alloy as the heat-transferring agent. These generators were subjected to severe thermal-cycle tests and at the same time to boiler water containing chloride concentrations of 1.8, 100, and 500 ppm. The thermal-cyclic test and 500 ppm chlorides in the boiler water of the second steam generator resulted in a 37% drop in heat-transfer rate. Cracks were observed in the tube sheet in the hot end of the steam generator, and a helium leak of  $0.7 \times 10^{-6}$  ft<sup>3</sup>/hr appeared between the steam and helium systems.

6.400

NP-5350

NATURAL CIRCULATION WITH NaK-56 IN FOUR VERTICAL UNBAFFLED HEAT  
EXCHANGERS. M. J. McGoff and J. W. Mausteller. Sept. 30, 1954.  
54p. Contract NObs-65426, Technical Report No. 32.

Natural convection cooling of tubes by NaK 56 (56 wt. %K) was investigated in four vertical un baffled heat exchangers. Three multitube exchangers contained either 0.125 to 0.250 in. OD tubes, and one exchanger contained a single 0.500 in. OD tube. The same exchangers were also tested under forced convection conditions. Natural circulation shell-side film coefficients ranged from 360 to 2,860 Btu/hr/ft<sup>2</sup>/°F, with corresponding Reynolds numbers of 475 to 19,500. A general correlation of natural circulation and forced circulation points was made for the three multitube exchangers. Natural circulation data for the single tube exchanger do not lie on the curve.

6.400

AD 212949

Heat Transfer Experiments with Sodium Potassium Alloy  
Jenkins, A. E. and McKee, G.  
United Kingdom Atomic Energy Authority (Gt. Brit.)  
March, 1955  
Declassified 1958. 6p.  
(Report No. R&DB(W)TN-198)  
TAB U59-112643

A description is given of experiments in which the heat transfer coefficient between two annuli each carrying a flow of sodium potassium alloy were measured. For Paclet numbers above 60 the results are in good agreement with the theoretical values given by Lyon (R. And D. B. (W) rept. 8054). For Paclet numbers below 60 the results do not agree with theory but are of doubtful accuracy. Circumferential temperature variations caused by eccentric positioning of one of the tubes of the exchanger have been measured for varying degrees of eccentricity. The maximum values obtained are only a fraction of those predicted by the simple theory.

NSA 13:9253

COMPACT REACTOR POWER PLANT WITH COMBINATION HEAT EXCHANGER -  
THERMOELECTRIC PUMP

E. A. Luebke and L. B. Vandenberg (Knolls Atomic Power Lab., Schenectady, N.Y.) July 7, 1954. Decl. with Deletions Feb. 19, 1960. Contract W-31-109-eng-52. 19 p.

A compact reactor power plant is described in which the reactor proper is located within a cylindrical heat exchanger. The pumping action in the liquid-metal-cooled system is obtained in combination with the heat exchanger function. By interposing thermoelements, a large thermoelectric current is generated in the heat exchanger by the temperature gradient normally existing between hot and cold tubes. With suitable pole pieces, the current produces a perpendicular magnetic field and develops sufficient force on the liquid metal for the desired pumping action.

NSA 15: 19031

NYO-3154

THE CONDENSING OF MERCURY AND SODIUM VAPOR AT ATMOSPHERIC AND LOWER PRESSURES. C. F. Bonilla and B. Misra. Nov. 1, 1954. 59p. Contract AT(30-1)-1042. CU-9-54-AT-1042-Ch.E. Proceedings of Heat Transfer Symposium sponsored by AIChE and ASME, Louisville, Ky., Mar. 20-23, 1955.

Heat-transfer coefficients were determined for Hg vapor condensing on both water and air-cooled vertical carbon steel, Cu-plated steel, Ni, type 304 and stainless steel condensers, 0.5 in. OD and 0.5 to 3 in. in length. Experiments were also carried out on a 4.5 in. long, 0.5 in. OD Ni--stainless steel composite tube condenser, both in horizontal and vertical positions. Visual observations, still photographs, and Fastax moving pictures showed film condensation on Cu-plated steel and Ni surfaces and dropwise condensation on stainless steel surfaces. On steel condensation was usually dropwise near the top and filmwise near the bottom. The heat velocity varied from about 25,000 Btu/hr/ft<sup>2</sup> at 0.5 psia with air cooling to about 750,000 at 15 psia with water cooling, while the heat-transfer coefficients ranged from ~ 3000 to ~ 10,000 Btu/hr/ft<sup>2</sup>/°F for film-type condensation and from about 4000 to over 100,000 for dropwise condensation. For measuring directly the temperature drop through the condensate film or from the vapor to the surface of the condenser, Fe-Hg and Ni-Hg differential thermocouples, as well as the Ni-stainless steel composition condensers themselves, were successfully employed. Condensing-heat-transfer studies for Na vapor were also carried out on a bi-metallic Ni--stainless steel condenser, using the condenser itself as its own thermocouple. The heat velocities varied from about 60,000 Btu/hr/ft<sup>2</sup> at 650°C to about 100,000 at 870°C, giving heat-transfer coefficients ranging from 11,000 to 13,000 Btu/hr/ft<sup>2</sup>/°F. The condensing-heat-transfer coefficients obtained for Hg and Na are only a small fraction of the Nusselt equation values for film-type condensation. 16 figures.

NYO-6217

NATURAL CONVECTION HEATING AND COOLING BY HORIZONTAL CYLINDERS: FINAL REPORT. C. F. Bonilla and J. P. Collins. June 1, 1953 6p. CU-11-53 Dep.; Ind. Dep.

Heat transfer coefficients for natural convection at horizontal cylinders were measured in the heating and cooling of water, mercury, and 40% and 60% aqueous sucrose solutions. No significant difference between heating and cooling could be found for steady state results, but direction of heat flow had considerable influence on the unsteady state correlations.

ANL-4092

REPORT FOR THE PERIOD MARCH 1, 1947 THROUGH NOVEMBER 30, 1947. Dec. 22, 1947. Decl. Dec. 13, 1955. 27p. \$6.30(ph OTS); \$3.00(mf OTS).

A section of this report considers the heat-transfer characteristics of a Na-K alloy-heated, vertical-tube boiler. The water and steam flowed on the inside of the tubes, and the liquid alloy was in contact with baffled plates on the outside of the tubes. Heat-transfer data were obtained experimentally and the constants calculated from the data. The maximum heat-transfer coefficient obtained was 807 Btu/(ft<sup>2</sup>)(°F)(hr).

REACTOR ENGINEERING DIVISION QUARTERLY REPORT [FOR] MARCH 1, 1953  
THROUGH MAY 31, 1953. June 15, 1953. Decl. with deletions Jan.  
17, 1957. 157p.

**Power Breeder Reactor.** Conceptual design studies for the Power Breeder Reactor indicate the feasibility of a contained primary coolant system in a package arrangement. One- and two-group calculations are presented in detail for preliminary PBR estimations. A technique for impregnating  $UO_2$  with NaK has been developed. The resulting putty-type fuel was successfully extruded through a 3/8-in. hole. Data are presented on the fuel element design factors imposed by heat transfer and cooling limitations for fuel plates, pins, and spheres. Fission heat liberated in the PBR blanket was estimated to be 7.7% of the total core power. Design criteria resulting from this estimate are analyzed. Heat exchanger size for the transfer of 500 Mw of heat from Na to NaK has been calculated for the intermediate exchanger and for the NaK-to- $H_2O$  steam generator.

BOILING AND CONDENSING OF LIQUID METALS; PROGRESS REPORT. C. F. Bonilla, J. S. Busch, H. T. Chu and B. Misra. Apr. 24, 1952. 12p. Contract AT(30-1)-1042.

Preliminary data have been obtained on the boiling at atmospheric pressure of a shallow layer of Hg on a horizontal iron-plated surface. The boiling film coefficient of heat transfer,  $h$ , ranged from 1600 to 8400 Btu/hr x ft<sup>2</sup> x °F. No film boiling was observed although a heat flow rate of 260,000 Btu/hr x ft<sup>2</sup> was reached. Hg vapor at atmospheric pressure was condensed on a short water-cooled vertical iron tube. Dropwise condensation was obtained, but seemed to impair the heat transfer, if anything, on account of the adherence of the droplets to the surface. Droplets ranged from 1 mm in diameter down to dust, and at intervals a slide would occur of all of the droplets on a given area. The condensing film heat transfer coefficients were very low, ranging from 220 to 530 Btu/hr x ft<sup>2</sup> x °F. They were apparently adversely affected by a mercury oxide film that built up on the surface, and/or by traces of noncondensable gas. More reliable data on the thermoelectric force of the thermocouple Fe-Hg have been obtained, which are approximately 10% higher than the previous results. The millivolts of a couple with its cold junction at 0°C and hot junction at  $t_3^0C$  is given, up to about 400°C, by  $E = 0.01939 t - 8.835 \times 10^{-6} t^2 - 9.675 \times 10^{-9} t^3$ .

QUARTERLY PROGRESS REPORT FOR OCTOBER 1 - DECEMBER 31, 1952,  
UNCLASSIFIED SECTION. 56p.

**Liquid Metal Heat Transfer.** The purpose of this project is to determine film heat-transfer coefficients for flow of Hg normal to a staggered tube bank. The individual test elements consist of an electrical resistance heating unit inserted in a 1/2-in. OD tube. This heating unit consists of Ni chrome wire wound on a Pyrex tube over which is placed a Pyrex sleeve. This sleeve is collapsed onto the inner rod by being heated to the melting point. The electrical input to the heating element will be supplied by a 250-v d-c motor-generator set. The annulus between the heater and the tube wall is to be filled with Hg for better heat transfer. The outer tubes of the test elements will be of two types: 347 stainless steel and chrome-plated Cu. There are 11 test locations in the lattice of 70 tubes with one element at a time being active. The active elements will be rotatable. This will allow the local and average film coefficient of heat transfer to be obtained, as well as the variation of coefficient through and across the lattice. (p.32-3).



HEAT EXCHANGE AT VERY LOW Pr NUMBERS. M. A. Stirikovich and I. E. Semenovker. Translated from Zhur. Tekh. Fiz. 10, 1324-30(1940). 13p.

Experiments are reported on heat transfer to Hg at 450 to 550°C flowing in steel tubes with diameters of 16 to 50 mm. The data are analyzed in terms of the Reynolds number: 150,000 to 350,000 in these experiments. The tubes are considered to have rough surfaces. The question of equivalent diameters in the case of very low Pr numbers discussed briefly on the basis of some additional experiments with annular apertures.

- 6.400 A COMPARATIVE ANALYSIS OF THE LIQUID METAL HEAT TRANSFER SYSTEMS FOR WMA. J. D. Selby. Apr. 20, 1949. Decl. Feb. 26, 1957. 84p. (KAPL-M-Fig.1: MEMO-JDS-1)

Design criteria are presented for heat transfer units for WMA (Intermediate Power Breeder). A comparative analysis was made of system size for use in setting up the final specifications for the heat transfer units. The reactor was designed to generate steam at a temperature of 550°F and 465 psia, including 90° superheat potentially capable of an efficiency of 28% in electrical output, and to use molten Na as the primary coolant. Factors investigated include the effects of heat exchanger size, steam pressure, and liquid metal flow rate on load rating and top reactor temperature. Specifications for the heat transfer system are outlined. No system recommendations are presented.

- 6.400 NP-5169  
HEAT TRANSFER WITH SODIUM-POTASSIUM LIQUID ALLOYS. Robert C. Werner, Earle C. King, and Robert A. Tidball. Dec. 5, 1949. 45p.

Over-all heat-transfer coefficients of 1000 to 2100 Btu/(hr)(ft<sup>2</sup>)(°F) were measured in a double-pipe heat exchanger using a 44 and a 77 wt. % K alloy of sodium and potassium. The data cover a temperature range of 300 to 1200°F and a velocity range of 1.5 to 12 fps in the center tube. A method is presented for separating the over-all coefficients into individual film coefficients. The coefficients calculated by this method, with the aid of the physical properties of sodium-potassium alloys presented, are then compared with the theoretical coefficients for liquids of low Prandtl number with very favorable results. Values of the individual film heat-transfer coefficients are found to vary from 2000 to 6000 Btu/(hr)(ft<sup>2</sup>)(°F) for the temperatures and velocities used. At temperatures up to about 1400°F, alloys of sodium and potassium will serve as excellent heat-transfer media because of their low vapor pressures, low viscosities, high thermal stability, high thermal conductivities, and melting points below room temperature.

- 6.400 See Also: 3.120, 2.300, 2.330, and 5.400.

6.500 OTHER COMPONENTS

6.500 DIGITAL MONITOR CHECKS REACTOR-FLOW RATIOS

H. Schlein (Atoms International, Canoga Park, Calif.)  
Nucleonics, 21: No. 1, 70-1 (Jan. 1963)

Circuitry and logical design of the triggering system of a digital computer that monitors the ratio of Na flow in the primary loop to Na flow in the secondary loop as part of the protective system of the Hallam Nuclear Power Facility are discussed.

NSA 17:8336

- 6.500 "Magnetohydrodynamic Journal Bearing", W. F. Hughes and R. A. Elco (Carnegie Inst. of Tech. Pitts) ARS (AME Rock. Soc.) Journal 32:776-8 May 62.

Analysis is presented for a magnetohydrodynamic pressurized journal bearing using liquid metal lubricant.

NSA 16:20570

- 6.500 BNL-756  
DESIGN AND FABRICATION OF A 2100°F FORCED CONVECTION Li TEST LOOP (Cb-lZr)  
Ivan L. Gray, Martin Marietta Corp., Nuclear Div., Second Annual High Temperature Liquid Metals Heat Transfer Technology Meeting, May 17-18, 1962

A progress report on the design, fabrication, and installation of a one-inch diameter Cb-lZr loop using EM pump flow to attain 20 gpm with lithium. The general design and arrangement are described as well as component development. The system operates within a vacuum chamber, 7 ft dia. by 19 ft long. Field welding of one inch Cb-lZr tubing by means of a rotating fixture which was purged with purified argon. Good quality, defect free welds were reported.

- 6.500 "Friction and Wear Behavior of Possible Bearing Materials In High Purity Na(l) at Temperatures to 500°C." W. H. Roberts (UK Atomic Energy Auth., Risley Lanc. Eng) Preprint Paper No. 3, London, The Institute of Mechanical Engineers, 1962, 10p.

A crossed-cylinder apparatus is described which enables basic friction and wear data for materials immersed in liquid metals, to be obtained. Results are presented for a selection of chrome alloys rubbed under boundary lubrication conditions in high purity Na, temperatures 200-500°C. The behavior of these combinations is compared with that in gases (CO<sub>2</sub> and He) under corresponding conditions of load, rubbing speed and temperature. Friction coefficients and wear rates were generally lower in Na, implying that the liquid metals provide a measure of lubrication between the rubbing surfaces. A striking feature of the results in Na is the manner in which wear rates increased fairly regularly with increased temperature for all rubbing combinations examined. This behavior is in complete contrast to that in CO<sub>2</sub> and He where wear-temperature curves varied markedly for different combinations. Experiments are described which were aimed at establishing the hydrodynamic lubrication did not materially contribute to the observed effect in Na.

NSA 16:29080

The feasibility of joining Mo-0.50 Ti-0.10 Zr by the fiber metal resistance brazing process was demonstrated. Metallic fiber compositions at the faying plane concentrate the heat at the interface, reducing the current required and thereby eliminating the two undesirable effects of temp. - - electrode-base metal bonding and recrystallization of the base alloy. Increased remelt temp. of the resistance brazed joint, due to local composition demonstrated as feasible but procedural improvements are indicated which should provide greater increases. Typical microstructures are presented for a number of brazing shim compositions, and a limited amount of mechanical property and remelt temp. data are presented.

- 6.500 MAGNETOHYDRODYNAMIC PRESSURIZATION OF LIQUID METAL BEARINGS  
Elco, R. A. and Hughes, W. F.  
(Carnegie Inst. of Tech., Pittsburgh)  
Wear, 5: 198-212 (May-June 1962) In English

The concept of the magnetohydrodynamic bearing is introduced and two types of bearings are analyzed. First a hydrostatic thrust bearing with an axial current-induced pinch is considered. It is shown that the load capacity can be increased and with no flow or external pressurization a load can be sustained because of the "pinch" effect. However, the magnitude of this pressurization is very small for physically practical values of current. The second bearing considered is the infinite inclined slider with an applied magnetic field parallel to the bearing surface and perpendicular to the direction of motion of the slider. For this type of bearing the pressure distribution, load capacity, and electrical characteristics are calculated and it is shown that useful electromagnetic pressurization can be obtained with reasonable values of magnetic pressurization can be obtained with reasonable values of magnetic field strength and current. (auth)

- 6.500 ON THE LOAD CAPACITY OF THE HYDROMAGNETICALLY LUBRICATED SLIDER BEARING  
Osterle, J. F. and Young, F. J.  
(Carnegie Inst. of Tech., Pittsburgh)  
Wear, 5: 227-34 (May-June 1962). In English

The load capacity of liquid metal lubricated slider bearings subject to an applied magnetic field transverse to the film is investigated. The optimum profile is determined and found to be the Rayleigh step form with the riser location and step height ratio dependent on the strength of the magnetic field. Load capacity is favored by large magnetic fields, small film thicknesses, and electrically insulating bearing surfaces. Only modest load increases can be obtained from conventional magnets of reasonable size. Subdeveloped superconducting electromagnets. (auth)

- 6.500 MAGNETOHYDRODYNAMIC JOURNAL BEARING  
Hughes, W. F. and Elco, R. A.  
(Carnegie Inst. of Tech., Pittsburgh)  
ARS (Am. Rocket Soc.) J., 32:776-8 (May 1962)

An analysis is presented for a magnetohydrodynamic pressurized journal bearing using a liquid metal lubricant. An external magnetic field is applied axially along the journal, and current is allowed to flow between the journal and bearing. It is found that significant increases in load carrying capacity can be achieved by supplying power from an external source. Open circuit conditions give no additional pressurization, and short circuit conditions result in a pressure decrease. (auth)

6.500 BNL-756

LIQUID METAL RESEARCH AT NASA-LEWIS RESEARCH CENTER

James P. Lewis, Lewis Research Center, Cleveland, Ohio  
Second Annual High Temperature Liquid Metal Heat  
Transfer Technology Meeting, BNL, May 17 and 18, 1962

The paper outlines the major liquid metals research and development efforts at Lewis Research Center. The work includes: a Two-Phase Sodium Loop for flashing sodium vapor; the Sodium Turbine Facility using refractory metals; Pump Test Facilities including one low pressure K pump and one high pressure Na pump; Alkali Metal Heat Transfer Facility using EM pumps and Cb-1Zr above 1500° F and type 316 stainless below; A Space Radiator and Condenser Facility using a NaK loop for boiling potassium; Bearing and Seal Studies using liquid Na environments; Mercury Programs relative to the radiator problem in zero gravity similar to SNAP VIII conditions; and several Materials Support Programs directed to advanced materials and refractory metals for all alkali metals, and Hg loop corrosion.

6.500 Lubrication Behavior of Liquid Metals, McDonald, Patrick H., and Whitfield, John K. May 61  
AD-268 442 (Contract AF.33(616)5885, Proj. 7022) (WADD TR 61-47)  
48 p.

The analysis presented for a finite length full-journal bearing is based on the hydrodynamic theory of lubrication developed by Reynolds (Phil. Trans. Roy. Soc. 177:157-234, 1886). A finite-difference relaxation procedure is obtained by machine computation. Solutions are obtained for the pressure distribution over the bearing area for various eccentricities in the hydrodynamic range. From the numerical results a simplified journal-bearing design criterion is established. Progress in the check out and assembly of the hydrodynamic lubrication test apparatus is reviewed. A discussion of the apparatus designed and built to study the boundary lubrication properties of liquid metals is given.

6.500 TID-7626 (Part 1)  
DEVELOPMENTS IN THE ANALYSIS OF OXYGEN IN ALKALI METAL

H. Kirtchik and G. Riechman (G.E. ARO)  
(NASA-AEC Liquid Metal Corrosion Meeting, Dec. 1961 at BMI)

In order to avoid false apparent oxide values due to the summation of total oxides, it was deemed necessary to develop a method of sampling. Efforts have been illustrated. (AGN Lib. 2-2786) NSA 16:16687

6.500 SPACE HANDBOOK TURBINES  
(NAA-SR-Memo-5615)  
J. Grimaldi (AI) Aug 29, 1960. 5p.

Turbine specific weight vs. power plant output was investigated for Rb, K, and Na at several inlet temperatures to obtain order of magnitude performance and weight of possible nuclear power plant systems.

NSA 15:8926

6.500 Lubrication Behavior of Liquid Metals, McDonald, Patrick H.  
North Carolina State College, Raleigh, N.C. NP-9184  
Progress Report 7 for May, 1960 to August, 1960  
August, 1960 (Contract AF 33(616)-5885

The assembly and check-out of the hydrodynamic-lubrication test apparatus (liquid metal and Argon loops) was completed. A method for obtaining a level suspension system for the test bearing was developed. A trolley system for moving the assembled bearing housing into and out of the support piping was designed and built. The fabrication of an apparatus to evaluate the effectiveness of liquid metals in the boundary-lubrication region was completed.

NSA 14:24217

6.500 Research on Liquid Metals and Other Unusual Materials (Sundstrand)  
J. R. May, NASA TN-D-769, 1960

K & Hg as bearing lubricants.

NSA 15:13283

6.500 COMMENTS ON THE APPLICATION OF ASME AND ASA BOILER AND PIPING  
CODES TO SODIUM SYSTEMS

W. C. Haynes, Sept. 15, 1959. 23 p. Contract AT-11-1-GEN-8.  
\$0.75 (OTS). Atomics International Div., North American Aviation,  
Inc., Canoga Park, Calif.

The American Society of Mechanical Engineers (ASME) Power Boiler Code, Unfired Pressure Vessel Code, and the American Standard Code for Pressure Piping (ASA B31.1-1955) are reviewed as bases for the design of sodium systems and to point out areas which may require consideration beyond the scope of these codes. It is concluded that the code rules are generally adequate in their intention to provide minimum safety requirements for new construction. However, the designer must have additional data in order to make realistic allowances for any unusual conditions which may be associated with sodium systems. It is also concluded that design criteria may, in some instances, be more appropriately based on the elevated temperature notched and unnotched properties of parent material, weld material, and the heat-affected zone, rather than just the unnotched parent material as provided for in the codes. (auth). NSA 13:21776

6.500 REALISATION D'UN ECHANTILLONNEUR A SODIUM LIQUIDE. (LIQUID SODIUM  
SAMPLER.) H. Chevilliard. Feb. 1959. 5p. (CEA-834) Dep.(mc).  
NSA 13:16752

6.500 NAA-SR-3638  
Control of Oxygen Concentration in a Large Sodium System  
Hinze, R. B.  
Atomics International Div., North American Aviation, Inc.  
Canoga Park, Calif.

1 December 1959, 45 p.  
Contract AT-11-1-GEN-8

Data on the performances of two types of cold traps in the 50,000 lb radioactive sodium system at the SRE are tabulated. The rates were determined when trap inlet oxygen concentrations were at 8 to 10 parts per million. Oxygen concentration was readily controlled to 8 ppm using a cold trap. Extraction of oxygen from sodium by zirconium at 1200 F (hot trapping) reduces the concentration below the limit of detection, i.e., oxide solubility saturation temperature below 225 F. The theoretical limit for the equilibrium oxygen concentration was calculated to be less than  $7 \times 10^{-6}$  ppm. The observed extraction rate of 0.009 lb oxygen/hr was one-half of the rate predicted from material behavior studies.

NSA 14:5071

6.500 TID-5788  
CONTROL AND DYNAMICS PERFORMANCE OF A SODIUM COOLED REACTOR POWER  
SYSTEM

Report No. 171 (Microetch Research Co., Cambridge, Mass.)  
P. D. Hansen and J. H. Eaton. Dec. 28, 1959, 185 p. for Alco  
Products, Inc. Contract AT(11-1)-666. OTS.

System controls...

NSA 14:15464

6.500 NAA-SR-4013  
SODIUM GRAPHITE REACTOR MATERIALS SURVEY  
B. R. Hayward (AI) September 15, 1959. 47p. Contract  
AT-11-1-GEN-8. \$1.25 (OTS)

This discussion reviews the general reactor concept and the specific materials used for the major reactor components.

NSA 13:21775

6.500 NAA-SR-3882 (AI)  
ELECTRICAL HEATING METHODS FOR LIQUID-METAL SYSTEMS  
R. S. Baker and H. W. Lohman  
Sept. 15, 1959, 16p  
Contract AT-11-1-GEN-8 #0.50 OTS.

The application of electric heating to liquid metal piping systems is discussed. Three electrical methods--are identified and described. Temperature variation along an induction heated pipe is explained as a magnetic phenomenon. A comparison of the three heating methods is offered.

NSA 13:21431

6.500 NAA-SR-4050. AI  
A. Siphon Break as a Blocking Valve  
J. McDonald and W. Marten

Runs were made with sodium at 500 and 940°F. The experiments were conducted to determine the feasibility of using the breaking of a syphon as a quick-acting means for stopping sodium flow following a loss of pump power.

NSA 14:1106

6.500 NAA - SR - Memo 2830  
Sintered Metal Filters for Sodium Coolant Systems  
McDonald, J. S.  
Atomic International, Div. of North American  
Aviation, Canoga Park, California. June 27, 1958, 10 p.

Equations which express the relations between the pressure drop, pore size, flow rate, and filter thickness for sodium flowing through sintered metal filters were derived.

NSA 14:19055

6.500 TID-3544  
DESIGN OF AN EDDY-CURRENT BRAKE FOR A SODIUM-COOLED NUCLEAR POWER REACTOR. R. S. Baker. Sept. 15, 1958. 17p. NAA-SR-2986  
\$0.75(OTS).

NSA 13:1815

6.500 Sampling and Analysis for Impurities to Liquid Sodium Systems, by J.R. Humpreys, Jr., Paper from "Liquid Metals Technology," Pt. I. Chemical Engineering Progress Symposium Series, p. 7-10.

Vacuum distillation apparatus and technique devised for sampling liquid sodium in reactor coolant systems and analyzing for oxides and metallic impurities. Equipment can be modified and used for Hg, Cs, Rb, K, Cd, Zn, Mg or Li. 13 references.

Metals Review, page 54, March 1958

6.500 ORNL-3168  
Oak Ridge National Laboratory, Tenn.  
Compatibility of Pump Lubricants with Alkali Metals and Molten Fluoride Salts by G. Goldberg A.S. Meyer, Jr. and J. C. White, Jan 14, 1957.  
Decl. Sept. 19, 1957, 16p. Contract W-7405-eng-26.

This report includes a description of an apparatus and a detailed procedure for testing the compatibility of pump lubricants with alkali metals and molten fluoride salts. Results are given for the reaction between certain pump lubricants at 200°F and molten sodium metal and molten fluoride salts at 1100°F

NSA 12:3653

6.500 AECU-3658  
Allis-Chalmers Mfg. Co., Milwaukee  
FUEL ELEMENT SUBASSEMBLY NOZZLE TEST IN HOT SODIUM FOR ATOMIC POWER DEVELOPMENT ASSOCIATES. 1957. 17 pages.  
U. S. Gov. Res. Repts. 30, No. 1, 52.

- 6.500 EDDY CURRENT TECHNIQUES FOR TESTING LIQUID METAL BONDING  
C. J. Renken, Jr. and W. J. McGonnagle (ANL) P. 273-7 of  
"Symposium on Nondestructive Tests in the Field of Nuclear  
Energy. Pres. in Chicago, ILL., April 16-18, 1957. ASTM Speical  
Technical Publication No. 223." Philadelphia, ASTM, 1958.

The technique described and the results presented show that this  
method is applicable and adequate for testing Na-bonded elements.

NSA 14:20431

- 6.500 AD 278193 Brazing and Bonding of Nb, Mo, Ta, W and Graphite, DMIC.  
Also same as DMIC-153.

- 6.500 COMPONENTS - HIGH PURITY SODIUM SYSTEMS (LASL)  
J. E. Kemme, p. 229-33 of Proceedings of the 1957 Fast Reactor  
Information Meeting Held at Chicago, Ill., Nov. 1957.

A series of small, pumped, Na loops were run to ultimately discover  
a means of purifying Na.

NSA 13:16600

- 6.500 Sampling and Analysis for Impurities to Liquid Impurities to Liquid  
Sodium Systems, by J. R. Humpreys, Jr., Paper from "Liquid Metals  
Technology," Pt. 1. Chemical Engineering Progress Symposium Series,  
p. 7-10. (1957)

Vacuum distillation apparatus and technique devised for sampling  
liquid sodium in reactor coolant systems and analyzing for oxides and metallic  
impurities. Equipment can be modified and used for Hg, Cs, Rb, K, Cd, Zn,  
Mg, or Li. 13 references. Metals Review, page 54, March 1958  
(also, CA 51:16199a)

- 6.500 Investigation of Liquid Metal Lubricated Bearings.  
Apkarian, Harry. GE, GE&CL, Schenectady, N. Y. Nov. 27,  
1950. Decl. Mar. 19, 1957 10p. R-50GL231.

The liquid metal lubricated bearing program was an investigation  
to determine (1) the feasibility of using liquid metals as bearing lubricants,  
(2) characteristics and behavior of bearings with liquid metal lubricants,  
and (3) design criteria for liquid metal lubricated bearings. The liquid  
metal lubricant used was a mixture of 50% Na and 50% K by weight. It was  
determined that liquid metals, such as NaK, when used as lubricants behave  
in accordance with established hydrodynamic principles in much the same  
manner as any conventional lubricant. Properly designed bearings lubricated  
by liquid metal will support practical loads through a wide range of temp-  
erature and speed.

NSA 12:1926

- 6.500 How to Take Samples from Liquid Metal Loops by Marx Weech and Gordon  
Fluke, (Univ. of Michigan, Ann Arbor).  
Nucleonics 15, No. 10, 112 (1957) Oct.

A sampler is described which gives leak-free performance and requires  
a minimum of operator attention. The sampler design will operate in either  
a high vacuum or an inert gas atmosphere of low or moderate pressure.

- 6.500 COMPONENTS: PIPING SYSTEM COMPONENTS  
F. A. Smith (ANL) p. 205-14 of Proceedings of the 1957 Fast Reactor  
Information Meeting held at Chicago, Ill., Nov. 20-21, 1957.

. . . no serious technical or economical limitation for the  
reliable operation of Na piping components at temperatures up to 1000°F.

NSA 13:16598

- 6.500 UCRL Design Data of General Interest. W. M. Brobeck and D. T. Scalise. September 1957. 102 p. (UCRL-3687)

Engineering data prepared and used at UCRL in design work are summarized. Included are curves for calculation of heat transfer by both free and forced convection and radiation curves for determination of pressure drop for laminar flow in forevacuum pipes; curves for determination of head loss in water flow in Cu and brass tubes and pipe and steel pipe; formulas and curves for the calculation of pumping speeds of pipes and orifices at high vacuum; a curve for the determination of heat transfer between contact surfaces in vacuum; convenient factors for use in cooling calculations; rules for the design of high pressure gas equipment; conversion charts for UCRL preferred heat transfer units; convenient factors for use in fluid flow calculations; charts for friction factors in pipe flow; charts listing the properties of the following metals at low temperatures: Al, Al alloys, Cu, Cu alloys, Ni, Ni alloys and stainless steels; curves for the calculation of heat transfer to water inside tubes; charts for the calculation of ultimate pressures of kinematic vacuum systems using rubber gaskets and other volatile materials; vapor pressure curves for Hg, Rb, Cs, As, K, Na, Zn, Cd, Tl, Mg, Ca (solid), Ca (liquid), Ba, Sr, Pb, Sb, Bi, Al, Si, Ag, Mn, Sn, Cu, Au, Ni, Co, Fe, C, Pt, Mo, and W; and thermal conductivity curves for Ag, Cu, Au, Al, Be, Mg, Mo, brass, "Dow FSI" (Mg alloy), Zn, Be-Cu alloys, Ni, Cd, Fe, carbon steel, Co, Pd, Pt, Cr, Ta, Sn, Pb, graphite, Bi, W, "Monel," and Stainless steel. 15 references.

- 6.500 KAPL-1177  
Knolls Atomic Power Lab., Schenectady, N. Y.  
Ceramic Insulation for Electromagnetic Pump Coils  
Sowman, H. G. and C. W. Krystyniak  
June 1, 1954. Changed from Official Use Only June 26, 1956. 26p.  
Contract W-31-109-Eng-52

A unique method of electrically insulating coils of an electromagnetic pump is described. Glass coatings on the Cu conductors were used as a means of turn to turn insulation. The insulation was composed of inorganic materials only. Successful tests were carried out at coil temperatures of approximately 500 C. Electrical resistances were found to be adequate and the thermal shock properties excellent. In addition, the glass coating provided considerable protection against oxidation for the copper conductors.

NSA 11:2475

- 6.500 Removal of Entrained Gas From a Sodium System  
Barker, K. R. and J. W. Mausteller  
Mine Safety Appliances Company, Callery, Penna. Technical Report No. 50  
Contract NObs-65426. 14p. July 12, 1956.

An efficient method for removal of entrained gas in a Na system similar to the S2G primary coolant system is described. A study of the behavior of air-water mixtures in a glass loop showed how gas moved through the system and gave a better understanding of two-phase flow. Air could be held up at various points depending on the velocity: down-stream end of upper horizontal run at 0.25 fps, in the vertical downward leg at 0.25 to 0.50 fps, and at the bottom of the vertical downward run at 0.50 fps. Entrained gas in the Na system caused erratic flowmeter and pump performance and flow stoppage at low velocities. An expansion tank located above the loop will remove gas at any flow condition great enough to transport gas to the vent. If it is necessary to transport gas downward to the expansion tank a minimum velocity must be exceeded. This was found to be between 1.5 and 2.3 fps in a 1 in. line 6 ft long. Gas removal rate is a function of velocity in the expansion tank like, but is independent of the main loop velocity. Entrained gas can be removed if liquid velocities are kept above 2 ft/sec and a normal separator is used in a by-pass line.



6.500 ORNL-2147  
Oak Ridge National Lab., Tennessee  
The Sampling of Alkali Metal Systems with the Modified MSA Sampler.  
Goldberg, G., et al.  
Sept. 10, 1956. 17p. Contract W-7405-eng-26

Two significant modifications have been made to the MSA alkali metal sampler: (1) the substitution of vacuum-tight, modified Wilson seal for the packing gland, and (2) the replacement of the gate valve with a vacuum-tight Teflon-packed, Jamesbury valve. A complete description of the modified sampler and a stepwise procedure for its application to the sampling of dynamic or static systems of alkali metals are given.

NSA 10:10194

6.500 KAPL-1079  
The Performance of Tungsten Carbide Journal Bearings  
Operating In Liquid Metals. Vail, D. B. Jan. 25, 1954.  
Changed from Official Use Only June 26, 1956. 49p.  
Contract W-31-109-Eng-52.

The results of a series of tests indicated that liquid-metal-lubricated journal bearing performance may be predicted adequately by existing theoretical and empirical concepts. Test performance of the journal bearings was closely correlated with the theoretical performance postulated by Cameron and Wood for a full journal bearing. The calculated minimum film thicknesses were also shown to be as empirically postulated by Cameron. In the range of boundary lubrication it was observed that tungsten carbide ceramal bearings resisted the immediate seizure characteristics shown by other alloys, but that some roughening of the bearing surfaces occurred for the particular ceramals used in this series of tests.

NSA 11:2448

6.500 TID-3544  
TYPE SS GA-3 ELECTRIC CABLE TEST WITH SODIUM. Memo Report 83. V. K.  
Heckel and E. C. King. May 9, 1955. 3p. NP-7403  
NSA 12:11846

6.500 NP-1527  
TECHNIQUE OF SAMPLING AND ANALYZING HOT FLOWING SODIUM-POTASSIUM  
ALLOYS (TECHNICAL REPORT IV). R. E. Lee and S. L. Walters.  
May 1, 1950. Decl. Apr. 21, 1955. 17p.

Included are a method by which samples of 80% K and 20% Na are taken at temperatures from 90° F to 1100° F, a method involved taking a sample from a flowing stream in a metal bucket and transferring with entire contents to an analytical apparatus and analyzed for O content, and data indicative of the solubility curve for O in NaK.

6.500 ANL-5345 (Del. 2)  
REACTOR ENGINEERING DIVISION QUARTERLY REPORT FOR PERIOD JULY 1, 1954  
THROUGH SEPTEMBER 30, 1954. Oct 15, 1954. Decl. with deletions  
Mar. 29, 1957. 127p.

Reactor Programs. The design of the Boiling Experimental Reactor is described. The Borax-I reactor was intentionally destroyed by suddenly adding 4% excess reactivity. Design of the Borax-II reactor is described. It will be used for studies of transient behavior and steady-state operation as a steam producer. A preliminary design configuration has been established in EBR-II employing central, inner, and outer blankets. Fuel geometries including a smaller pin-type element are being investigated. Supporting Design, Research, and Development. The accuracy of diffusion theory for fast reactors was investigated. Water corrosion tests have been performed on high-U alloys, Zr- and Ti-base alloys, and Ni-plated Al plates. Thermal cycling tests were performed on fuel rods and pin-type fuel elements. Results are reported on tests on a current conductor connection for a high-temperature d-c electromagnetic pump, on Na valves with conventional packing, and on a rod-gripper test facility for the EBR-II. A vacuum cup sampler for high-temperature Na and NaK systems is described. Lifting and loading mechanisms for the EBR-II working model are described.

6.500 NP-5613  
PERFORMANCE TESTS OF THERMAL INSULATION FOR SODIUM PIPING.  
Memo Report No. 72. Walter Milich, R. C. Andrews, and E. C. King,  
Dec. 21, 1954. 9 p. Contract NObs-65426

Samples of Kaolin Wool, LK-61, Superex, Thermoflex RF-1400, and Unibestos No. 1200 were immersed in Na under an inert atmosphere at 350, 500, and 850°F for 16-minute periods. At 850°F Na penetrated and charred all of the insulations. Kaolin Wool and Thermoflex were the least effected at the lower temperatures. Samples of baked and unbaked LK-61, Superex, and Unibestos No. 1200 were tested for mechanical strength under wet and dry conditions. Unibestos proved to be the strongest of the insulations tested in either wet or dry conditions.

6.500 Basic Information on the Bearing Properties of Various Materials in Liquid Metals. Greenert, W. J. and Gross, M. R.  
NEES, Annapolis. EES-090014A 19 Feb. 1954, 28p. AD-146169

Evaluation of materials for use in antifriction bearings exposed to liquid sodium-potassium alloy is presented. In order to establish certain basic information, however, many of the tests described were performed in lubricating oil. Data represented on the load carrying capacity of SAE 52100Q and 18-4-1 high speed tool steel in oil at 400 F. Superiority for the high speed tool steel was found. Also, the plastic behavior of rollers subjected to high stresses is discussed, and dispersion in the results of the contact roller test is statistically analyzed. The effect of liquid metal on laminated phenolic and glass laminated melamine plastics is presented. It is concluded that the maximum operating temperatures for these materials is 275 F. Results are also presented on the effect of liquid metal on the fatigue strength of SAE 521000 steel. The conclusion is that liquid sodium-potassium is not detrimental to the fatigue properties of this steel.

NSA 13:14508

6.500 AECU-3200  
Massachusetts Inst. of Tech., Oak Ridge, Tenn.  
Engineering Practice School  
Vapor Traps for Handling Liquid Sodium  
Erickson, A. J. et al  
August 25, 1951, 11p. For Carbide and Carbon Chemical Div. (K-25 Plant).  
Contract W-7405-Eng-26. Subcontract 70 (KT-109)

Proposals for removing Na aerosol by an electrostatic precipitator, a copper coil condenser, and a bubbler were tested and evaluated. All were at least partially effective, the condenser proving to be the most practical to operate.

NSA 11:3885

6.500 KAPL-M-FNS-6  
Knolls Atomic Power Lab., Schenectady, N. Y.  
Use of a D-C Electromagnetic Pump as a Throttling Device in a Sodium System. Schell, F. N. Aug. 13, 1953. 11p. Contract W 31-109-Eng-52

Operation of a d-c pump as a dynamic brake (magnetic drag) in a Na system proved successful. The Na flow from the 50 gpm test pump was reduced by 26 percent and the pressure at the inlet of the test pump was lowered from 15 psia to 2.7 psia. A comparison between the performance of the d-c unit as a pump and as a generator is presented.

NSA 10:10958

6.500 See Also: 2.300 thru 2.350, and 3.212, 3.222, 3.232, 3.242

6.500 TM 3388-67  
A 1000 HOUR TEST OF A CORROSION PRODUCT SEPARATOR UNIT IN A  
HAYNES ALLOY NO. 25 LOOP CONTAINING MERCURY (TEST G-16)  
J. F. Nejedlik, Thompson-Ramo Wooldridge, Inc., March 9, 1962.

One of the major unsolved problems affecting the life of the SNAP II Power Conversion System is the mass transfer of corrosion products by mercury and subsequent deposition. It is feared that the corrosion products might tend to accumulate in critical areas such as orifices, bearings and so forth. Therefore, this test was conducted to evaluate a corrosion product separator and to determine the influence of corrosion product removal on corrosion rate.

The corrosion product separator was successful in removing 85 percent of the elements corroded from the container walls. The loop and separator, both fabricated from Haynes alloy No. 25, operated for 1000 hours. The mercury was boiled and condensed at 1100°F, superheated to 1190°F and subcooled to 325°F. The flow rate in this loop was much higher than in previous loops, being approximately 37 pounds of mercury per hour as contrasted with approximately 12 pounds of mercury per hour. No increase in corrosion rate was noticed as a result of the higher flow rates and velocity or by the removal of corrosion products. If this type of separator or an improved type works equally as well in the final application, the danger of failure from corrosion products should be greatly reduced.

6.500 CROLOY 9M CORROSION PRODUCT SEPARATOR LOOP  
First Progress Report Covering Period April 24 to June 1, 1963.  
Contract NAS 3-2538. D. B. Cooper and E. J. Vargo, Thompson-Ramo Wooldridge, Inc.

The primary objective of this program is that of determining the feasibility of utilizing corrosion product separation techniques in support of the SNAP-8 program.

6.500 ER-5302  
SUNFLOWER SOLAR RANKINE SYSTEM MERCURY CORROSION AND CORROSION  
PRODUCT SEPARATOR STATUS SUMMARY. (TAPCO) April 16, 1963  
Presented at NASA, Lewis Research Center on the general topic of Mercury Corrosion and Corrosion Product Trapping Experience at TAPCO.

The report has been centered primarily around the effects and test results which have been noted to date on the mercury Rankine cycle systems. Corrosion product separators are discussed and their results analyzed.

7.000

TECHNIQUES OF  
CORROSION TESTING

- 7.000 Corrosion by Liquid Metals  
by Epstein, Leo F.,  
from "Progress in Nuclear Energy, Series 4, Technology and  
Engineering," Vol. 1, Edited by R. Hurst and S. McLain, McGraw-Hill,  
1956. Chapter 6, pp. 366-77. Epstein, Leo F.

The utilization of fused metals as heat transfer media in nuclear reactor systems has focused attention on the great advantages which can be attained by using these high thermal conductivity fluids, and has emphasized the importance of investigating the corrosion problems which they produce. Liquid metals are currently being used in mercury vapour boilers, in automobile and airplane valves, and elsewhere, and the study of corrosion effects with these substances goes back at least 30 years. The extremely high heat transfer requirements of nuclear reactors has resulted in an intensive and accelerated investigation of these effects over the last 10 years, particularly with liquid sodium and Na-K alloys. These investigations have been carried out in the U.S. at a number of the national laboratories of the USAEC, several universities and a large number of industrial organizations.

Experimental techniques for determining corrosion rates in static (isothermal) and dynamic systems, where there is a  $\Delta T$ , are described, and details of the results of experience with mercury, sodium and Na-K alloys are presented. The behaviour of materials in lithium, lead, bismuth and gallium are also discussed briefly.

There appear to be two basic processes involved in the phenomenon of corrosion by liquid metals (1) chemical reaction and (2) solution. The latter in turn may be divided into two classes (2a) where the rate of attack is determined by the heterogeneous diffusion of solute atoms across the solid-liquid interface ("solution rate limited") and (2b) where the rate of corrosion is fixed by the homogeneous diffusion of the solute through the solvent fluid ("diffusion limited"). Equations for the dependence of these various kinds of corrosion phenomena on temperature, fluid flow velocity, the geometry of the system and similar factors are presented.

A few special topics in liquid metal corrosion are also touched upon, namely: (a) heterometallic effects; (b) welding and diffusion bonding; (c) carburization and nitridification; and (d) corrosion of compounds and non-metallic materials.

---

## 7.100 STATIC CORROSION MEASUREMENTS

- 7.100 TRIAL MANUFACTURE OF AN EXPERIMENTAL NaK SYSTEM  
Y, Imai, et al., (Tohoku Univ., Sendai). J. Atomic Energy Soc.,  
Japan 2, 127-35 (1960) Mar. (In Japanese).

Static testing of NaK in stainless steel led to the system described. (More on the abstract).

NSA 14:13830

- 7.100 STATIC SODIUM CORROSION TESTS OF CERAMIC MATERIALS  
(KAPL)  
L. R. McCreight Report No.: KAPL-MEMO-LRM-2. (July 6, 1951)

Static Liquid-Metal Corrosion. Interim Report (covering) the Period July 1949- September 1952. by Brasunas, Anton deS and W. D. Manly, ed. May 11, 1954. Decl. March 12, 1957. 99p. Contract W-7405-eng-26.

Static corrosion tests have been made in molten sodium, lithium, lead, bismuth, and several alloys containing uranium. Temperatures have been varied, but the bulk of the data is concerned with tests made at 1000°C (1832°F). Sodium was found to be the least corrosive in static and dynamic tests, and almost all alloys tested have shown good corrosion resistance. Lithium, on the other hand, attacked many alloys quite severely, especially nickel-containing alloys. Thermal gradient dynamic tests have also shown lithium to be much less attractive than sodium because of the susceptibility to mass transfer. Lead and bismuth were quite similar to lithium in many respects, both in static and dynamic corrosion tests, and are compatible with very few metals at 1000°C (1832°F).

NSA 11:9747

STRENGTH OF ALLOYS IN CONTACT WITH SODIUM

Kishkin, S. T. and Benediktova, G. P. (Translation)

The mechanical strength of a number of alloys operating in contact with sodium at high temperatures was investigated. Short-term and long-term tests were carried out with hollow, sodium-filled steel specimens. Results of short-term tests at 1000°C showed that sodium-filled samples yield a negligible increase in ultimate strength and a decrease in the plasticity of the alloys. According to long-term test data the limit of long-time strength of the alloys remained the same or increased. (M.C.G.)

7.110 EARLY CAPSULE TESTSInteractions Between Solid and Liquid Metals and Alloys

Eldred, V. W.

Atomic Energy Research Estab. (Gt. Brit.) X/R 1806, 220pp. (1955).

An investigation was made of the corroding effect of liquid Hg on Cr, Fe, and Co; of liquid K on Mg, Ag, Al, W, Cr, Cu, Fe, Co, and Ni; of liquid Na on Mg, Ag, Al, W, Cr, Cu, Fe, Co, Ni, and some ferrous and non-ferrous alloys; of Sn on Cr and ferrous and non-ferrous alloys; of Bi on Al, Ag, W, Cr, Cu, Fe, Co, and ferrous and non-ferrous alloys; of Cd on Cr, Fe, Co, and ferrous and non-ferrous alloys; of Pb on Ag, Al, W, Cr, Cu, Fe, Co, Ni, and ferrous and non-ferrous alloys; and Zn on ferrous and non-ferrous alloys. The tests were carried out at temperatures up to 550°, for periods of contact up to 300 hours. The filtered liquid metal was forced into glass tubes containing clean bars of the solid metal, under controlled atmosphere. Previous work, recent work done elsewhere, and the author's results were considered to discuss the characteristics of metals and alloys showing a high corrosion resistance to liquid metals. The experimental evidence indicated that inert systems have a difference of at least 50 in the Hildebrand solubility parameters of the 2 components. The rate of attack by solution of the solid in the liquid was considered in detail for the first time. Five possible processes for the attack of a liquid metal on a solid metal were presented. 200 references.

7.120 TESTING OF SEVERAL MATERIALS IN ONE LIQUID METAL CAPSULE

To be expanded in the supplement

7.130 SINGLE MATERIAL CAPSULE TESTS

- 7.130 Liquid Metals Work Summary, R. W. Carpenter, Aerojet-General Nucleonics, BMI Conference on Alkali Metals. Apr. 1961.

Covers 1) static corrosion capsule tests, 2) proposed loop program, and 3) thermodynamic measurements.

- 7.130 Summary of Work at Aerojet-General Nucleonics on Liquid Metal Corrosion (NASA-AEC Liquid Metals Corrosion Meeting. Dec. 1961 at BNL)

Six liquid metal programs reviewed. TID-7626 (Part 1)  
(AGN Lib. 2-2786)

- 7.130 ORNL-3226  
ANP PROJECT PROGRESS REPORT, MAY 1, 1961 TO JUNE 30, 1961  
p. 10 and 11

- (a) 310 - refluxing K capsule test.  
(b) 316 - boiling K loop test.

- 7.130 ORNL-3144  
ANP PROJECT SEMI-ANNUAL REPORT, APRIL 30, 1961  
p. 21-23

- (a) 310 and Inconel-refluxing K capsule test.  
(b) Description of Inconel and Haynes Alloy #25 loops.

- 7.130 COMPATIBILITY OF MATERIALS WITH HIGH TEMPERATURE POTASSIUM, FIRST QUARTERLY PROGRESS REPORT, MAY 1 THROUGH JULY 31, 1960  
(NP-10146) (Rocketdyne Div., North American Aviation, Inc., Canoga Park, Calif.) Aug 31, 1960. Contract NAS 5-453. 35p.  
(R-2617-1)

Several preliminary static capsule tests were made at 2000°F using Hastelloy-X as capsule material and He as internal atmosphere. The results for the Nb-Al<sub>2</sub>O<sub>3</sub> compatibility test run for 350 hr revealed a hardness increase and a small surface layer formed on the Nb tab. Results for the Nb-K compatibility test run for 25 hr indicated a slight weight loss in the wrought Nb tab - amounting to 0.83 and 1.43 mg/cm<sup>2</sup> day, and metallographic examination revealed no discernable attack on either Nb or Hastelloy-X by K. Dynamic capsule and loop equipment for future compatibility studies and mechanical property tests to be used are described. (D.L.C.)

NSA 15:18504

- 7.130 ORNL-1729 (Del.)  
AIRCRAFT NUCLEAR PROPULSION PROJECT QUARTERLY PROGRESS REPORT FOR PERIOD ENDING JUNE 10, 1954  
July 29, 1954 Decl. with Deletions Nov. 12, 1959, 114 p.  
Contract W-7405-eng-26. OTS.

The static, seesaw and thermal convection loops were used to test corrosion resistance of various materials in liquid metals. Includes Na.

NSA 14:23226

- 7.130 COMPATIBILITY OF MATERIALS WITH HIGH TEMPERATURE POTASSIUM  
(NP-10005) Second Quarterly Progress Report, August 1 through October 31, 1960. (Rocketdyne Div., North American Aviation, Inc., Canoga Park, Calif.) Nov. 30, 1960 Contract NAS 5-453. 31p.  
(R-2617-2)

Refractory metals were evaluated for potential use in high-temperature, turboelectric space power plants using potassium as the working fluid. In isothermal capsule tests to 2000°F, corrosion of wrought niobium and niobium-1% zirconium alloy was negligible except when the metals were combined with nickel alloys. In 50 hours of Rankine loop tests to 1800°F, molybdenum resisted attack best of the refractory metals tested. Limited mechanical properties tests are described. Two niobium alloy loops are under construction, and the first vacuum chamber is complete.

NSA 15:16060

## 7.200 DYNAMIC CAPSULE TECHNIQUES

- 7.200 GE 63 FPD66  
ALKALI METALS BOILING AND CONDENSING INVESTIGATIONS  
VOL. II - MATERIALS SUPPORT  
J. W. Semmel, Jr., W. R. Young, and W. H. Kearns  
Space Power and Propulsion Section, GE Co., Cincinnati 15, Ohio.  
Final Report for Period January 1, 1961 to June 30, 1962.  
Published January 14, 1963

Materials support was provided for alkali metals boiling and condensing investigations which required the construction of a 300 KW heat transfer loop from L-605 and a 100 KW loop from the Cb-1Zr alloy. In addition to the preparation of specifications for these materials and assistance in constructing the heat transfer facilities, experimental investigations were conducted to document several aspects of the materials behavior which were pertinent to the loop construction and operation. Experimental work was performed in the following areas: 1) Aging and embrittlement of L-605, 2) Corrosion of L-605 by potassium, and 3) Corrosion and diffusion bonding of Stellites No. 6 and No. 12 hard facing materials in potassium.

AGN Lib. 3-2299

- 7.200 MATERIALS COMPATIBILITY  
E. E. Hoffman, W. H. Cook, et. al., ORNL-2988 (p. 221-43)

Studies to determine the compatibility of type 304 stainless steel and beryllium in a NaK environment were conducted at 1112, 1292, and 1472°K. A program to investigate the compatibility of boiling potassium with several potential container materials at 1600°F. Refluxing K capsule tests with metallographic and weight-change data is presented. A boiling-K-type 316 stainless steel loop test for 200 hrs at 1500°F resulted in no attack on the loop. An additional test was run for 1800 hours at 1600°F. Tests include the solubility of container materials in an alkali metal and the rate of solution of the container material. Thermal convection loop studies were being planned.

NSA 15:537

- 7.200 Liquid Metal Research  
NASA-Lewis (NASA-AEC Liquid Metals Corrosion Meeting, Dec. 1961 at BNL)

Hg corrosion loops and capsules; includes solubility study.  
TID-7626 (Part 1) (AGN Lib. 2-2786)



- 7.200 NUCLEAR ENGINEERING DEPARTMENT, PROGRESS REPORT, SEPTEMBER 1-  
DECEMBER 31, 1960  
(BNL-659), May 1961. Contract AT(30-2)-Gen-16. 69 p.

Heat transfer rates measured on the new loop for the flow of Hg through unbaffled rod bundles and results of an analytical study of heat transfer to liquid metals flowing in concentric annuli are reported. The operation of loops and capsules for testing materials in liquid metals is described.

NSA 15:30331

- 7.200 HIGH-TEMPERATURE CORROSION BY COOLANTS (BNL)  
D. H. Gurninsky and C. J. Klamut, NASA TN D-769, 1960

Na and Hg corrosion, Zr inhibitors, solubility studies, and a variety of capsule and loop tests.

- 7.200 Liquid and Vapor Alkali-Metal Corrosion (BMI)  
E. M. Simons, NASA TN-D-769, 1960

Data for NaK capsule, NaK loop, Na loop, Na purity, Na as a lubricant, K vapor, K liquid and vapor.

NSA 15:13279

- 7.200 Liquid Metals Research Program (NASA-Lewis), L. Rosenblum,  
NASA TN-D-769, 1960

Na and K capsule tests, Na and K loops, purification of alkali-metals, Na critical point experiment.

NSA 15:13280

- 7.200 ORNL-1647  
Oak Ridge National Lab., Tenn.  
Static Liquid-Metal Corrosion. Interim Report (covering) the  
Period July 1949- September 1952. by Brasunas, Anton deS and W. D.  
Manly, ed. May 11, 1954. Decl. March 12, 1957. 99p.  
Contract W-7405-eng-26.

Static corrosion tests have been made in molten sodium, lithium, lead, bismuth, and several alloys containing uranium. Temperatures have been varied, but the bulk of the data is concerned with tests made at 1000°C (1832°F). Sodium was found to be the least corrosive in static and dynamic tests, and almost all alloys tested have shown good corrosion resistance. Lithium, on the other hand, attacked many alloys quite severely, especially nickel-containing alloys. Thermal gradient dynamic tests have also shown lithium to be much less attractive than sodium because of the susceptibility to mass transfer. Lead and bismuth were quite similar to lithium in many respects, both in static and dynamic corrosion tests, and are compatible with very few metals at 1000°C (1832°F).

NSA 11:9747

---

7.210 SEESAW OR AGITATED CAPSULES

- 7.210 AI Memo 6416, Experimental Apparatus and Techniques  
for High Temperature Compatibility Studies, W. T. Smith, May 31,  
1961.

The development of apparatus and lab technique for study of materials compatibility with 1500-2200°F. K was attempted. Techniques for corrosion tab prep., dry box capsule filling, and sampling and vacuum filling and sampling are described. Apparatus for rotating capsule testing to 2000°F, and to 2400°F and anisothermal "see-saw" capsule testing is also described.

NSA 16:27586

- 7.210 Dynamic Liquid-Metal Corrosion Studies (SRI)  
W. D. Weatherford, Jr., NASA TN-D-769, 1960

Hg gravity flow, two-phase test loop.

NSA 15:13285

7.210

ORNL-1934

An Evaluation of the Corrosion and Oxidation Resistance of High-Temperature Brazing Alloys. E. E. Hoffman et al., Nov. 7, 1956. Decl. Oct. 9, 1959. 40p. Contract W-7405-eng-26-OTS.

In evaluating the corrosion and the oxidation resistances of a brazing alloy for a specific application, emphasis was placed on the see-saw-corrosion and cyclic-oxidation studies. The Ni-Cr-Si alloy was compatible with sodium.

NSA 14:1804

7.210

ORNL-1729 (Del.)

AIRCRAFT NUCLEAR PROPULSION PROJECT QUARTERLY PROGRESS REPORT FOR PERIOD ENDING JUNE 10, 1954

July 29, 1954 Decl. with Deletions Nov. 12, 1959, 114 p. Contract W-7405-eng-26. OTS.

The static, seesaw and thermal convection loops were used to test corrosion resistance of various materials in liquid metals. Includes Na.

NSA 14:23226

7.210

Oak Ridge National Lab., Tennessee

A Simplified Apparatus for Making Thermal Gradient Dynamic Corrosion Tests. (Seesaw Tests). Brasunas, Anton DeS. March 13, 1952. 7p. Contract (W-7405-eng-26).

A simple device has been developed in which mass transfer and dynamic corrosion studies can be made with molten metal, hydroxide, fluoride, or any other molten medium. The test specimen, a metal tube approximately one-third full of the liquid under study, is gently rocked in a manner resembling a seesaw, so that the fluid flows by gravity to either end of the tube. One end is maintained at some suitable high temperature, whereas the other end is maintained at some low temperature. After many such cycles, the tube may be sectioned for inspection.

NSA 10:8855

7.210

SODIUM; A NONCORROSIVE COOLANT. R. F. Koenig and S. R. Vandenberg. (1951). 17p. (AECU-1495). Metal Prog. 61, 71-5(1952).

A general description of the corrosive properties of Na is presented and several corrosion tests are described. Examples of five types of attack on containers by liquid metals are mentioned. The steps followed in making a static corrosion test are discussed, and descriptions of four types of dynamic tests are included, namely, rotating specimen (whirligig), thermally circulated loops (harps), forced-circulation loops, and surveillance coupons in operating heat-transfer systems. Four methods of determining the effect of Na immersion on mechanical properties of construction materials are outlined. Eight forms of test apparatus are illustrated by photographs or diagrams.

---

## 7.220 THERMAL CONVECTION TECHNIQUES

7.220 MATERIALS COMPATIBILITY WITH MERCURY AT TEMPERATURES BELOW 1000°F  
J. J. Owens and J. F. Nejedlik (TAPCO) Presented on February 22  
at the 1962 AIME Meeting (at New York City) "Corrosion by  
Metal Heat Transfer Liquids Symposium.

- a) Low Carbon, 5% Cr, and austenitic stainless steels to 1200°F in natural convection harps.
- b) Effects of various additives on the corrosion rate of low carbon steel.
- c) Bent reflux tubes of Pyrex at temperatures of 1000°F and internal Hg vapor at 180 psi.
- d) Two phase natural circulating type loops: ferritic and austenitic stainless steel, and Haynes 25 alloy. (43 Ref.)

---

## 7.230 BOILING AND CONDENSING TESTS

7.230 ORNL-3029  
ANP PROJECT SEMIANNUAL REPORT - OCTOBER 31, 1960  
p. 14

(a) 316- boiling K and Haynes Alloy #25- boiling K capsule tests, (with inserts) operated for 500 hours at 1500°F. Wt. losses in vapors (Haynes #25 - 4.6 mg/inch<sup>2</sup>; 316 - 1.1 mg/in.<sup>2</sup>) wt. gains in liquid - 2.4 mg/in.<sup>2</sup>.

(b) Inconel- boiling K. Capsule tests with inserts 1600°F, 1000 hours. Wt. loss in vapor: 10 mg/in.<sup>2</sup>. Grain boundary attack: 10 mils.

(c) 316- boiling K loop, 3000 hours, 1600°F, 50 ft/sec vapor flow, 180 gm/min mass flow.

7.230 Alkali Metal Corrosion Studies (Rocketdyne), R. J. Teitel,  
NASA TN-D-769, 1960

Na and K loops, corrosion rates reported on various materials of containment. Bent reflux capsule tests were also completed.

NSA 15:13276

7.230 Boiling Alkali Metal and Related Studies (ORNL)  
E. E. Hoffman, NASA TN D-769, 1960.

Na and K corrosion, K purification, K loop tests, and refluxing capsules.

NSA 15:13281

7.230 ORNL-2942  
ANP PROJECT SEMIANNUAL REPORT, APRIL 30, 1960  
p. 13 - 15

(a) 316 - boiling K capsule test (100 hours, 1600°F). No inserts. Tabs at vapor, liquid-vapor interface, and liquid regions. Tantalum foil getter at bottom of capsule. Weight changes on tabs: vapor and liquid region tabs...no weight change. Liquid-vapor interface tab: +2.8 mg/in.<sup>2</sup>. No attack per metallography.

7.230 MONTHLY REPORT NO. 1, JULY 1953, TO DETROIT EDISON COMPANY.  
Aug. 11, 1953. 10p. (NP-5477).

Corrosion tests with liquid Na on a group of special fuel alloy test specimens were conducted in two corrosion harps. The design of the harps is emphasized.

7.230 NRL-Memo-581  
Naval Research Lab., Washington, D. C.  
Evaluation of Croloy Steel for Sodium Use by Brown, B. F. March 23, 1959. 14 p. Project No. NS200-021

The resistance of Croloy 2 1/4 to corrosion by Na was studied in thermal convection harps. The results of these tests indicate that there is no mass transfer of Croloy 2 1/4 at 500°C (923°F) maximum temperature with a delta T of 175°C (315°F), no decarburization of Croloy 2 1/4, no carburization of Type 347 stainless steel in the presence of Croloy, and no detachable difference in effect of O concentration in Na at 0.003 wt. % and 0.014 wt. %.

NSA 11:5311

7.230 ER-4103  
THE SNAP II POWER CONVERSION SYSTEM TOPICAL REPORT No. 7.  
MERCURY MATERIALS EVALUATION AND SELECTION  
(TID-11,307), J. J. Owens et al., October, 1960. 143p.  
Thompson-Ramo-Wooldridge, Inc., Cleveland, Ohio.

This report presents the results of a two-year material compatibility study and discusses the corrosion mechanisms involved in a system in which mercury is the working fluid. Includes 35 references and 11 bibliographies. (AGN Lib. 2-5632)

NSA 15:21096

---

### 7.300 LOOP CORROSION TESTS

7.300 AGN-8034 Uncl.  
Aerojet-General Nucleonics, San Ramon, California  
DESIGN AND OPERATION OF 1800°F PUMPED BOILING RUBIDIUM LOOP SYSTEM  
AND DETERMINATION OF DENSITY AND VAPOR PRESSURE RUBIDIUM BETWEEN  
174° and 1800°F.  
Space Power Systems Technology Studies: Rubidium, Corrosion  
and Physical Properties Evaluation Program. Final Report  
(Report No. 16). February 1, 1960 - May 31, 1961. 173p.  
NSA 16:14834

7.300 NUCLEAR ENGINEERING DEPARTMENT, PROGRESS REPORT, SEPTEMBER 1-  
DECEMBER 31, 1960  
(BNL-659), May 1961. Contract AT(30-2)-Gen-16. 69 p.

Heat transfer rates measured on the new loop for the flow of Hg through unbaffled rod bundles and results of an analytical study of heat transfer to liquid metals flowing in concentric annuli are reported. The operation of loops and capsules for testing materials in liquid metals is described.

NSA 15:30331

- 7.300 Liquid-Metals Research Program (NASA-Lewis), L. Rosenblum,  
NASA TN-D-769, 1960

Na and K capsule tests, Na and K loops, purification of alkali-metals,  
Na critical point experiment.

NSA 15:13280

- 7.300 Liquid and Vapor Alkali-Metal Corrosion (BMI)  
E. M. Simons, NASA TN-D-769, 1960

Data for NaK capsule, NaK loop, Na loop, Na purity, Na as a  
lubricant, K vapor, K liquid and vapor.

NSA 15:13279

- 7.300 CF-54-9-98 ORNL  
Examination of Sodium, Beryllium, Inconel Pump Loops Numbers 1  
and 2. G. M. Adamson and E. Long. Sept. 13, 1954. Decl.  
Oct. 9, 1959. 12p. Contract W-7405-eng-26. OTS.

From data obtained from two loops, the use of beryllium in  
inconel systems containing molten sodium appears feasible if the tempera-  
ture is held below 1200°F.

NSA 14:2690

- 7.300 SODIUM; A NONCORROSIVE COOLANT, R. F. Koenig and S. R. Vandenberg.  
(1951). 17p. (AECU-1495). Metal Prog. 61, 71-5(1952).

A general description of the corrosive properties of Na is presented  
and several corrosion tests are described. Examples of five types of attack  
on containers by liquid metals are mentioned. The steps followed in making a  
static corrosion test are discussed, and descriptions of four types of dynamic  
tests are included, namely, rotating specimen (whirligig), thermally circulated  
loops (harps), forced-circulation loops, and surveillance coupons in operating  
heat-transfer systems. Four methods of determining the effect of Na immersion  
on mechanical properties of construction materials are outlined. Eight forms  
of test apparatus are illustrated by photographs or diagrams.

#### 7.310 THERMAL CONVECTION LOOPS

- 7.310 MATERIALS COMPATIBILITY WITH MERCURY AT TEMPERATURE BELOW 1000°F.  
J. J. Owens and J. F. Nejedlik (TAPCO) Presented on February 22  
at the 1962 AIME Meeting (at New York City) "Corrosion by Metal  
Heat Transfer Liquids Symposium.

- a) Low Carbon, 5% Cr, and austenitic stainless steels to  
1200°F in natural convection harps.
- b) Effects of various additives on the corrosion rate of low  
carbon steel.
- c) Bent reflux tubes of Pyrex at temperatures of 1000°F and  
internal Hg vapor at 180 psi.
- d) Two phase natural circulating type loops: ferritic and  
austenitic stainless steel, and Haynes 25 alloy. (43 Ref.)

- 7.310 CORROSION OF STAINLESS STEEL TUBES BY LIQUID SODIUM SYSTEMS, I.  
THERMAL CONVECTIONAL CORROSION TESTING APPARATUS  
Hideo Atsumo (Hitachi, Ltd., (Japan)). Nippon Gen-Shiryoki  
Gakkaishi, p. 94-9 (Feb. 1962) (In Japanese).

A new type thermal convection corrosion testing apparatus was set up to study liquid sodium corrosion of stainless steel. In order to investigate several factors simultaneously, thermal calculation and structure of the apparatus and welding methods of the test pieces in NaK circulating loops was examined. Long term corrosion testing of 18-8 stainless steel tubes by high temperature NaK was effected quite well by this method.

NSA 16:13538

- 7.130 ORNL -3160  
METALLURGY DIVISION ANNUAL PROGRESS REPORT, MAY 31, 1961  
pp. 73-74

(a) Refluxing capsules, 500 and 1000 hours at 1500 and 1600°F on Inconel, Haynes Alloy #25, types 310 and 316, type 316 shows best resistance to attack.

(b) 316-K loop, 3000 hours, 1600°F, results of metallographic examination, chemical results.

- 7.310 ER-4103  
THE SNAP II POWER CONVERSION SYSTEM TOPICAL REPORT No. 7  
MERCURY MATERIALS EVALUATION AND SELECTION  
(TID-11,307), J. J. Owens et al., October, 1960. 143p.  
Thompson-Ramo-Wooldridge, Inc., Cleveland, Ohio.

This report presents the results of a two-year material compatibility study and discusses the corrosion mechanisms involved in a system in which mercury is the working fluid. Includes 35 references and 11 bibliographies. (ACN Lib. 2-5632)

- 7.310 NUCLEAR ENGINEERING DEPARTMENT PROGRESS REPORT, MAY 1, AUGUST 31,  
1960  
(Brookhaven National Lab., Upton, N. Y.) 66 p.

Includes: liquid metal heat transfer, steel thermal convection loops containing Hg and Na, Mercury Test Loop, and NaK Heat Transfer Loop. (J.T.J.)

NSA 15:20477

- 7.310 TESTING HEAT TRANSFER AND CORROSION OF GLOBEIRON FOR FUEL CLADDING  
IN A Na-COOLED FAST BREEDER. R. H. Jones and R. E. Lee.  
Nucleonics 13, No. 2, 70-2(1955). Feb.

Heat transfer and corrosion tests show that Globeiron is satisfactory as a thin-walled fuel-cladding material for 30 day exposures in a sodium-cooled fast reactor. The tests, conducted in the apparatus in Fig. 1, simulated reactor operation in which 500°F sodium entered 0.165-in. -o.d. 10 mil-wall Globeiron tubes was heated in an average heat flux, which was produced by hot NaK, varied from  $1 \times 10^6$  to  $3 \times 10^6$  Btu/ft<sup>2</sup>/hr over the 13½-in. exposed length of specimen.

- 7.310 ORNL-1729 (Del.)  
AIRCRAFT NUCLEAR PROPULSION PROJECT QUARTERLY PROGRESS REPORT FOR  
PERIOD ENDING JUNE 10, 1954  
July 29, 1954 Decl. with Deletions Nov. 12, 1959, 114 p.  
Contract W-7405-3ng-26. OTS.

The static, seesaw and thermal convection loops were used to test corrosion resistance of various materials in liquid metals. Includes Na.

NSA 14:23226

- 7.310 ORNL-1108  
METALLURGY DIVISION QUARTERLY PROGRESS REPORT FOR PERIOD ENDING  
31 JULY 1951  
E. C. Miller and W. H. Bridges (1952) (UC-25, pp. 27-29, 72)

Testing 1010 steel, Haynes 25 and V-36 in lithium at 1020-1100°C for 280 hrs.

- 7.310 ORNL-1033  
METALLURGY DIVISION QUARTERLY PROGRESS REPORT FOR PERIOD ENDING  
30 APRIL 1951  
E. C. Miller and W. H. Bridges (1951) (UC-25 pp. 40-52 , 70-72)

Static testing of containment materials exposed to lithium as well as the following: thermal convection loops of 316 SS, 304 SS, 347 SS, 310 SS, 321 SS, Haynes 25, 1010 iron, Ni-A, and Inconel were tested up to 1000 hrs at temperatures ranging from 1100 to 1500°F. Types 347 SS, 310 SS, and 321 SS showed least resistance to attack of the 300 series.

- 7.310 ORNL-987 (Del.)  
METALLURGY DIVISION QUARTERLY PROGRESS REPORT FOR PERIOD ENDING  
31 JANUARY 1951  
E. C. Miller, W. H. Bridge (1952) UC-25, pp. 3848, 67

Testing in Na at 1350 and 1500°F up to 1000 hours.

- 7.310 ORNL-919 (Del.)  
AIRCRAFT NUCLEAR PROPULSION PROJECT QUARTERLY PROGRESS REPORT  
FOR PERIOD ENDING DECEMBER 10, 1950  
C. B. Ellis and W. B. Cottrell  
Feb. 27, 1951, Decl. with deletions Nov. 10, 1959. 160 p.

Both 316 and 347 stainless steel convection harps containing liquid Na have operated 800 hours at 1500°F without failure.

NSA 14:18644

- 7.310 ORNL-910  
METALLURGY DIVISION QUARTERLY PROGRESS REPORT FOR PERIOD ENDING  
31 October 1950  
E. C. Miller and W. H. Bridges (1951)(p. 38-42)

Dynamic loop corrosion tests (HARPS): 316 SS, 304 SS, L-605, Ni, 347 SS, and low carbon 321 at 1350 - 1500°F.

Thermal convection loops with: 310, 446, Inconel, 316 SS ELC, V-36 Co based alloy, L-60 Co based alloy, 310 SS shrouded with 1010 iron, V-36 shrouded in 1010 iron, and L-605 shrouded with 1010 iron.

Further materials to be tested: 310, 405, 430, 446, Ni grade A, Inconel, 316 SS ELC, 410, 430 ELC, 321, Ni grade L, and Inconel X. These compatibility will run 100 hours at approximately 1100°C.

- 7.310 ORNL-858 (Del.)  
THE AIRCRAFT NUCLEAR PROPULSION PROJECT QUARTERLY PROGRESS REPORT  
FOR PERIOD ENDING AUGUST 31, 1950  
C. B. Ellis and W. E. Thompson  
Dec. 4, 1950, Decl. with deletions Oct. 1959, 64 p.

Stainless steel harps were operated both under thermal connection and with an electromagnetic pump using Na and NaK.

NSA 14:18643

7.320 ELECTROMAGNETIC PUMPED LOOPS

- 7.320 RUBIDIUM EVALUATION PROGRAM  
Quarterly Technical Report No. 3 for Period Feb. 1 through April 30, 1960.  
P. F. Young (Aerojet-General Nucleonics, San Ramon, Calif.)  
April 30, 1960, 26 p. Contract AT(04-3)-251, Project No. 5. (AGN-8007)

NSA 15:15961

- 7.320 RUBIDIUM EVALUATION PROGRAM  
Quarterly Technical Report No. 6 for Period May 1 through July 31, 1960  
P. F. Young (Aerojet-General Nucleonics, San Ramon, Calif.)  
July 30, 1960, 31 p. Contract AT(04-3)-251, Project No. 5. (AGN-8016)

NSA 15: 15962

- 7.320 AGN-8034 Uncl.  
Aerojet-General Nucleonics, San Ramon, California  
DESIGN AND OPERATION OF 1800°F PUMPED BOILING RUBIDIUM LOOP SYSTEM  
AND DETERMINATION OF DENSITY AND VAPOR PRESSURE RUBIDIUM BETWEEN  
174° and 1800° F  
Space Power Systems technology Studies: Rubidium, Corrosion and Physical Properties Evaluation Program. Final Report (Report No. 16). February 1, 1960 - May 31, 1961. 173 p.  
NSA 16:14834

7.330 CENTRIFUGAL AND OTHER MECHANICAL PUMP SYSTEMS FOR  
HIGH FLOW RATE LOOPS AND SYSTEMS

To be expanded in the supplement

7.340 BOILING AND CONDENSING LOOP SYSTEMS

- 7.340 ORNL-3270  
SPACE POWER PROGRAM SEMI-ANNUAL PROGRESS REPORT - DECEMBER 31, 1961  
pp. 91-104

Boiling K: (a) Good summary of all natural circulating loops, (b) pressure - temperature profile on Inconel loop, (c) metallographic, wt. change, and chemical results on Inconel and Haynes Alloy #25 loops, and (d) description of pumped loops.

- 7.340 ORNL-3226  
ANP PROJECT PROGRESS REPORT, MAY 1, 1961 TO JUNE 30, 1961  
p. 10 and 11

(a) 310 - refluxing K capsule test.  
(b) 316 - boiling K loop test.

- 7.340 ORNL-3144  
ANP PROJECT SEMIANNUAL REPORT, APRIL 30, 1961  
p. 21-23

(a) 310 and Inconel-refluxing K capsule tests.  
(b) Description of Inconel and Haynes Alloy #25 loops.



- 7.340 COMPATIBILITY OF MATERIALS WITH HIGH TEMPERATURE POTASSIUM, THIRD QUARTERLY PROGRESS REPORT, NOVEMBER 1, 1960 THROUGH JANUARY 31, 1961 (NP-10147) (Rocketdyne Div., North American Aviation, Inc. Canoga Park, Calif.) March 3, 1961. Contract NAS 5-453. 62 p. (R-2617-3)

Fabrication of loop equipment for studies of compatibility between Nb-1%Zr and liquid K is described. Results of a low temperature loop run are presented for Ta, Nb, Nb-1%Zr, and Mo, with Mo showing the least change. Results are also presented for bi-metal couples in K (Nb and Nb-1%Zr) and for alloy capsules (D.L.C.).

NSA 15:18505

- 7.340 NASA TN D 1188  
MERCURY CONDENSER RESEARCH AND DEVELOPMENT. Presented at the Government-Industry Conference on Mercury Condensing. April 18, 1961. A. Koestel and J. J. Reinmann, TAPCO, April 1961.

Presented in this summary report are space condenser design criteria, basic design data, a description of condensing mercury research test apparatus with related analysis, and test results for both ground and zero-gravity tests. (AGN Lib. 2-752)

- 7.340 NASA TN D 1188  
PRESSURE DROP IN TWO-PHASE FLOW. Presented at the Government-Industry Conference on Mercury Condensing. April 18, 1961. C. Baroczy and J. Sells, A.I. April 1961

Presents an attempt to determine a better method of correlation of the pressure drop data, and to obtain additional condensing pressure drop data. The second activity that is currently being undertaken is to obtain additional condensing pressure drop data of greater accuracy.

- 7.340 NAA-SR-6303  
THE SNAP II POWER CONVERSION SYSTEM - TOPICAL REPORT NO. 11. ORBITAL FORCE FIELD BOILING AND CONDENSING EXPERIMENT. TAPCO ER-4443, P. E. Grevstad, 15 January 1960. Prepared under Subcontract N843FS-101221 for A.I.

This report provides the basis for a program to investigate the characteristics of Rankine space power plants in the zero gravity aspect of the environment of space. It justifies the need for this work by presenting the expected effects on Rankine space power plants. Discussions of experimental techniques for studying these phenomena show that this information can be obtained rapidly and economically. (AGN Lib. 2-2296)

- 7.340 HW-63052  
BEHAVIOR OF A BOILING METAL THERMOSIPHON LOOP (GE-HAPO)  
G. Jansen, Jr. Dec. 1, 1959, 34 p. Contract AT(45-1)-1350. OTS.

The boiling characteristics of the system Pb-Bi eutectic-Hg were studied in a one-inch ID quartz tube containing a two-foot column of metal...

NSA 14:12654

7.340 ZERO GRAVITY BOILING AND CONDENSING

Lloyd M. Hedgepeth (Wright-Patterson Air Force Base, Dayton, Ohio)m  
Paper No. 1322-60. Pres. at the ARS Space Power Systems Conference,  
Santa Monica, California, Sept. 27-30, 1960. New York, American  
Rocket Society, 1960. 15 p.

A brief history is presented of the zero-gravity boiling and condensing test effort at WADD. This history is then brought up to date; and, in all cases, an account of the phenomenon occurring during the tests is given along with a possible explanation. Significant observations from the latest flights also are included along with preliminary plans for future tests.

NSA 15: 2754

7.340 See Also: 1.330, 1.340.

---

7.400 TECHNIQUES FOR EVALUATING CORROSION EFFECTS

7.400 AI Memo 6416, Experimental Apparatus and Techniques for High Temperature Compatibility Studies, W. T. Smith, May 31, 1961.

The development of apparatus and lab technique for study of materials compatibility with 1500-2200°F. K was attempted. Techniques for corrosion tab prep., dry box capsule filling, and sampling and vacuum filling and sampling are described. Apparatus for rotating capsule testing to 2000°F, and to 2400°F and anisothermal "see-saw" capsule testing is also described.

NSA 16:27586

7.400 Cambridge Univ. (England) INTERACTIONS BETWEEN SOLID AND LIQUID METALS AND ALLOYS; SECOND ANNUAL TECHNICAL REPORT, by V. W. Eldred. Sept. 1951. 72p (AERE-X/M-85)

A method has been developed for bringing clean surfaces of fully annealed metals in contact with filtered and degassed liquid metals and keeping them in contact for long periods, without oxide contamination, so that the rate and nature of the attack by the molten metal may be investigated. The method can be used with many of the lower melting point metals at temperatures below 500°C and may be extended to higher temperatures. Tests have been carried out at temperatures up to 400°C on pure metal systems in which little attack was anticipated. A few tests have also been included on systems in which severe attack was expected. The interpretation and practical application of the results are discussed. (auth)

NSA Vol. 6 - 6603

7.400 Investigation into Carbon Atoms Mobility and Atomic Interaction in Alloys by Use of Tracer Technique. Presented at the International Conf. on Radioisotopes in Scientific Research Sept 9-20, 1957 at Paris. No. UNESCO/NS/RIG/28. P. L. Gruzin, Y. F. Babikova, Y. A. Polikarpov and G. B. Fedorov. London Pergamon Press, Ltd., 1957 (20 p)

NSA 12:1437

7.400 See Also: 3.300, 2.310, and 2.320.

---

7.410 DIMENSIONAL AND MASS TRANSFER MEASUREMENTS

To be expanded in the supplement

---

## 7.420 ANALYSIS OF LIQUID AND PRECIPITATED PHASES

- 7.420 GEAP-4006, SODIUM MASS TRANSFER: III The Applic. of  $\text{NH}_3$  (1) as a Sodium Leaching Agent. H. W. Alter and P. A. McManus (G.E. Co. Vallecitos At. Lab., San Jose, Calif.) Apr. 62 Contract AT(04-3) 189, 16p

A technique is presented for  $\text{NH}_3$  liquid leaching of metallic sodium from corrosion coupons, filter elements, & Na samples to reveal contaminants and impurities. The advantages of the method in preserving the physical form of corrosion of mass transfer deposits are demonstrated. A possible application to the determination of trace  $\text{O}_2$  in Na is mentioned.

NSA 16:22047

- 7.420 See Also: 3.300 thru 3.340, and 6.160.
- 

## 7.430 METHODS FOR EVALUATING CORROSION NON-DESTRUCTIVELY

- 7.430 APPLICATION OF THE "TOTAL REPLICA" TECHNIQUE TO DETECTION OF DEFECTS ON THE INNER SURFACE OF TUBES  
Alfille, L., Azam, M., and Fignon, M. (Gen. Elec. Co. Hanford Atomic Products Operation, Richland, Wash.) from Rev. met., 58: 429-36 May 1961 (HW-TR-27) 22 p.

Methods for the rapid detection of small defects on the inner surface of cladding tubes were investigated. It was concluded that nondestructive visual examination of a replica of the inner surface was best suited for large-scale observations. Formation of the replica by direct casting and by rotational wetting is described. Removal and treatment of the replica and examination of the surface are discussed. The technique of a total replica by the method of rotational wetting appeared to give the best results.

NSA 16:393

- 7.430 See Also: 6.150, 6.160, and 6.170.
- 

## 7.440 CHEMICAL EVALUATION OF CONTAINMENT MATERIALS

- 7.440 See Also: 1.400, 1.420, 1.610, 2.110, 2.120, 3.400, and 1.430.
-

FOR EVALUATING CORROSION AND ASSOCIATED MATERIAL CHANGES

- 7.450 EFFECTS OF EXPOSURE OF AUSTENITIC AND FERRITIC STEELS IN SODIUM MASS TRANSFER TEST LOOPS\*, R. S. Young, T. Lauritzen, E. G. Brush, GE-APED, 12<sup>th</sup> Annual AEC Corrosion Symposium, May 20-22, 1963, Castlewood, Pleasanton, California

Continuation of a program at General Electric, APED, under AEC contract has provided the opportunity for extensive examinations of steel samples exposed to flowing sodium in six test loops. 316 stainless steel, 2½Cr-1Mo and 5Cr-½Mo-½Ti steel test samples were exposed at temperatures between 600°F and 1200°F, also low and high oxygen sodium at various velocities were used. Loops are constructed of the three test materials to provide a series of mono-metallic and bi-metallic systems in order to obtain information relative to the use of these materials in sodium-cooled reactor systems.

Carburization of 316 stainless steel, decarburization of 2½Cr-1Mo steel, preferential movement of chromium and nickel with respect to iron, and austenite-to-ferrite transformation were noted. In general, with the exception of observed carbon changes, the weight changes observed in 316 stainless steel hot-leg systems (316 SS, 2½Cr-1Mo, or 5Cr-½Mo, - ½Ti cold-legs) are reflected by the measured changes in surface concentrations of the major alloying constituents. Measurements of changes in surface composition and concentration gradients of these constituents in 316 stainless steel by x-ray fluorescence and electron microprobe techniques confirm and chart the growth of metallographically visible surface ferrite layers.

The mass transport of carbon in the bi-metallic systems containing 2½Cr-1Mo steel cold legs is dependent primarily upon the availability of a carbon sink such as provided by the 316 stainless steel.

\* This work was performed under Contract USAEC AT(04-3)-189, P.A.#15. This paper presents information in extension of that presented in May 1962 on the same subject, Metallurgical Changes in Mono- and Bi-Metallic Sodium Mass Transfer Test Loops at the 11th Annual AEC Corrosion Symposium.

- 7.450 ORNL-3313  
METALLURGY DIVISION ANNUAL PROGRESS REPORT MAY 31, 1962

Inconel- boiling K loop test, 1600°F, 1500 hour. Metallographic, wt. change, and chemical analyses results.

- 7.450 AD277904 Oxide Nucleation and Growth. Cornell U, Ithaca, N. Y.  
W. H. Orr, 1 Apr 1962.

Although the interaction of oxygen with a clean metal surface is usually interpreted in terms of homogeneous chemisorption, careful kinetic measurements of the very initial take-up of O by a clean Mg surface indicate that the 1st stage of the process is dominated by nucleation and growth of the oxide phase at certain preferred sites on the metal surface. This interpretation is supported by observed structure of the oxide film. The Wagener flow method was used to study the kinetics of oxide film formation at very low O<sub>2</sub> pressure from 77 to 304°K. The structures of the metal surface and oxide film were studied by electron microscope and electron diffraction. During the 1st stage of oxidation the sticking probability, "S", increased with take-up of O<sub>2</sub>. Once the oxide islands had grown together, the sticking probability decreased as the oxide film thickened. During both stages of the oxidation process, the sticking probability was independent of the O<sub>2</sub> pressure.

7.450 AGN-8051  
RUBIDIUM CORROSION CAPSULE PROGRAM. QUARTERLY TECHNICAL REPORT.  
NOVEMBER 1, 1961 - JANUARY 1962, REPORT No. 4  
Arabian, Robert V.  
(Aerojet-General Nucleonics, San Ramon, Calif.)  
Contract AT (04-3)-368. 9p.

Tests are being carried out to obtain corrosion and solubility data on various containment materials for rubidium at temperatures from 1000 to 2000 F. Progress is reported on corrosion and solubility test runs, test analysis, and analytical procedures. (M.C.G.)

7.450 ORNL-3160  
METALLURGY DIVISION ANNUAL PROGRESS REPORT, MAY 31, 1961  
pp. 73-74

(a) Refluxing capsules, 500 and 1000 hours at 1500 and 1600°F on Inconel, Haynes Alloy #25, types 310 and 316, type 316 shows best resistance to attack.

(b) 316-K loop, 3000 hours, 1600°F, results of metallographic examination, chemical results.

7.450 NP - 5449  
Report No. 7, March 1, 1954 Thru May 7, 1954 to the Detroit Edison Company. J. R. Taylor, S. J. Rodgers, and H. J. Williams  
July 25, 1954. 37 p.

A 30-day test on Zr tubing produced a metallic deposit on a large portion of the outer or NaK contacting surface. The deposit was found to be very magnetic, and a chemical analysis showed that it was 75% Fe. The deposit formation was believed to have been caused by a form of mass-transfer due to the coexistence of a temperature differential and metals (type-316 stainless steel) having temperature-dependent solubilities in NaK. Weight and dimensional determinations made on the specimen tube before and after exposure showed no appreciable gain or loss of weight nor change in wall thickness. A metallurgical examination of the exposed Zr specimen the presence of black needle-like spider-web constituent which appeared to be at the grain boundaries penetrating to as much as half the thickness of the tube from the Na contacting side. This constituent was thought to be Zr hydrides. An examination by polarized light showed that recrystallization took place in all sections of the tube. A change in grain structure on the Na contacting surface was also evident with polarized light. An examination of the type-347 stainless steel IHX tube showed no erosion or corrosion and the tube structure was normal. An average concentration of 1.8 ppm of Zr at the sampling temperature was found in metal samples taken from the Na stream during the test. A total of less than 1 mg of Zr was found in Na and NaK cold traps analyzed at the conclusion of the tests, indicating that the amount of tube material lost to the liquid metals during the 30-day test was negligible.

7.450 ORNL-1215  
HEAT TRANSFER AND PRESSURE LOSS IN THE TUBE BUNDLES FOR HIGH  
PERFORMANCE HEAT EXCHANGERS AND FUEL ELEMENTS  
G. H. Cohen, A. P. Frass and M. E. LaVerne. Aug. 12, 1952  
Decl. Oct. 9, 1959, 75 p. Contract W-7405-eng-26. OTS.

The heat transfer characteristics of one heat exchanger was determined with NaK. Includes a metallographic examination of heat exchanger after 3000 hr operation in NaK, and dynamic systems at approximately 1500°F or 850°C.

NSA 14:2218

7.460 CHANGES IN MECHANICAL AND PHYSICAL PROPERTIES

- 7.460 AN APPARATUS FOR OBSERVING CRACKING AND CREEP IN ZIRCONIUM ALLOY SPECIMENS WHEN IMMERSSED IN MOLTEN Na or NaK  
(NAA-SR-Memo-5261)  
D. M. Lonneaux (AI) May 6, 1960. 4p. OTS.

A study was made of vessel designs to test zirconium alloy specimens under tensile stresses sufficient to produce 2% elongation while immersed in molten alkali metals and to externally measure the creep of the specimens.

NSA 15:6202

- 7.460 See Also: 1.500, 21.110, 2.120, and 2.130.
-

8.000

BIBLIOGRAPHIES - REPORTS OF PROCEEDINGS  
AND SYMPOSIUMS - GENERAL COMPENDIUMS  
OF LIQUID METALS TECHNOLOGY





8.000      GEST-2012  
NOTES ON LIQUID METAL STUDIES IN FRANCE AND GREAT BRITAIN.  
Leo F. Epstein, (GE-VAL) January 15, 1963. Contract No. NASr-108

This document is a summary of observations made in laboratories engaged in liquid metal work. Attention is directed to ideas and techniques applicable to NASA and U.S. programs which have been developed in Europe. Names and addresses of British and French workers are included. Includes NaK and Na.

8.000      HIGH TEMPERATURE LIQUID METAL TECHNOLOGY REVIEW  
A Bimonthly Technical Progress Review  
BNL 788 (PR-1)

Prepared under the auspices of Division of Reactor Development, Engineering Development Branch, USAEC Vol. 1, Number 1, February 1963. (BNL) Associated Universities, Inc. under contract with the USAEC. (Propulsion Systems and Energy Conversion-TD 4500, 19th Ed.).

8.000      NASA TN D 1188  
GOVERNMENT - INDUSTRY CONFERENCE ON MERCURY CONDENSING on  
April 18, 1961, Pasadena, California. Published February 1962  
162 p.

Some of the specific topics discussed were gravity effects and ground testing; test apparatus and measuring techniques; prediction of pressure drop; flow stability; physics of condensing; and effect of non-condensable gases (AGN Lib. 2-752)      NSA 16:14354

8.000      NP-12288  
DEFENSE METALS INFORMATION CENTER SELECTED ACCESSIONS  
P. B. Plate, Comp. (BMI) Oct. 1962 Contract AF33(616)-7747. 95 p.

A bibliography of 186 references is presented on high-strength alloys, light metals, nonmetallics, refractory metals, coatings, applications, and composites. (liquid metals included)

NSA 17:6518

8.000      NP-12417  
DEFENSE METALS INFORMATION CENTER SELECTED ACCESSIONS  
P. B. Plate, Comp. (BMI) Nov. 1962 (Contract AF33(616)-7747)  
78 p.

A total of 153 annotated references is presented covering the following subjects: high-strength alloys, light metals, nonmetallics, refractory metals, coatings, applications, and composites. Numerical, author, and subject indexes are provided. (liquid metals included)

NSA 17:6521

8.000      WADC-TR-53-373 (Suppl. 9)  
A REVIEW OF THE AIR FORCE MATERIALS RESEARCH AND DEVELOPMENT PROGRAM  
Donna J. Tate (Aeronautical Systems, Div. Metals and Ceramics Lab., Wright-Patterson AFB, Ohio)  
October 1962, 250 p.

Basic and applied research in the materials area being conducted by the Metals and Ceramics, nonmetallic materials, Physics, Manufacturing Technology, and Applications Laboratories of the Directorate of Materials and processes are covered.

NSA 17:6532

8.000 KAPL-200-19  
REACTOR TECHNOLOGY REPORT No. 22 - CHEMISTRY  
Knolls Atomic Power Lab., Schenectady, N. Y.  
Sept. 1962. Contract W-31-109-eng-52. 107p.

Five sections are included for which separate abstracts were prepared. (J.R.D.)

8.000 BNL-728 Uncl.  
Brookhaven National Laboratory, Upton, New York.  
Proceedings of the Eleventh Annual AEC Corrosion Symposium  
May 23-25, 1962, J. R. Weeks, ed. 69p.  
... liquid metals ... NSA 16:20975

8.000 THE EFFECT OF MOLTEN ALKALI METALS ON CONTAINMENT METALS AND  
ALLOYS AT HIGH TEMPERATURES  
Amateau, M. F.  
Defense Metals Information Center, Battelle Memorial Institute  
DMIC Report 169, May 28, 1962. 54 p.

Extensive review of literature on the effects of Na and NaK alloys, liquid Li and liquid and gaseous K, Rb and Cs on the corrosion and sliding and bearing properties of pure metals and alloys including stainless steel, superalloys and refractory metals. Topics include types of liquid-metal corrosion, factors affecting liquid-metal corrosion and techniques for investigating such. 71 ref. (R6m, 2-62; SGA-h, SS, EG-d37)

8.000 BNL-661, Table of Reactor Coolant Properties, Green, Leon,  
March 10, 1961

Selected properties of coolants currently being considered for use in nuclear reactors are presented. Physical, chemical, and nuclear properties that must be considered in selecting reactor coolants are listed. Data on cost, material compatibility, toxicity, non-nuclear hazards are also given. A number of combined parameters were evaluated that are helpful in comparing such important criteria as low pampering power, wide temperature range, low induced activity, and moderating properties. Included is a bibliography listing references to additional data.

8.000 NUCLEAR FUELS AND MATERIALS DEVELOPMENT  
(Div. of React. Development AEC) Feb. 1961, 172 p (TID-11295)

Included in this summary is the corrosion of cladding materials in liquid metal and the effect of O<sub>2</sub>, N<sub>2</sub>, and H<sub>2</sub> on the mechanical properties of Cb was investigated.

NSA 15:12475

8.000 SOVIET RESEARCH ON CORROSION OF SPECIAL ALLOYS  
(Office of Technical Services, Washington, D.C.) July 7, 1961  
148 p. (OTS-61-31480).

An evaluation is presented of current Soviet capabilities in the corrosion of special alloys, with particular attention to materials used in the construction of aircraft and nuclear reactors. It is based primarily on a survey of approximately 1500 references from the Soviet technical literature of the period 1950 to 1960. (liquid metals?)

NSA 17:6572

8.000 SB-449, Cooling and Coolants for Electrical and Electronic  
Equipment, Turbines and Reactors, (OTS Selective Bibliography),  
(1961).

A bibliography is presented of reports which are listed in U. S. Government Research Reports and Technical Translations.

- 8.000 ASD-TR-61-594  
LITERATURE SURVEY ON LIQUID METAL BOILING FINAL REPORT - PHASE I  
Balzhiser, Richard E., Clark, John A., Colver, C. Phillip, Hucke,  
Edward E., Merte, Herman Jr., Smith, Lowell, R., and Teller, Andrew S.  
(Michigan University, Ann Arbor, College of Engineering) December  
1961. Contract AF 33(616)-8277. 157p. (AD-270481)

A survey was made of information pertaining to the current status of liquid-metal-boiling technology. Material pertaining to boiling and two-phase flow phenomena are also included, and existing correlations for predicting heat transfer coefficients in the nucleate- and film-boiling regimes are summarized. Correlations which predict the critical heat flux (or burnout flux) are presented and compared with experimental data available. The use of liquid metals as fluids in space-oriented Rankine cycles is considered, and interfacial considerations of possible importance are cited and discussed. Particular attention is called to the solid-liquid interfacial energy and its importance in limiting heat transfer across the interface. A summary of physical properties for various liquid metals and water is presented along with 1191 references to books, reports, journals, and theses published from approximately 1930 to 1961. (P.C.H.)

- 8.000 TID-7626 (Pt. I) Uncl.  
National Aeronautics and Space Administration, Washington, D. C.  
and Atomic Energy Commission, Washington D. C.  
NASA-AEC Liquid Metals Corrosion Meeting (held) December 14-15,  
1961, Brookhaven National Laboratory, Upton, Long Island,  
New York, 193p. NSA 16:16676 AGN Lib: 2-2786
- 8.000 MND-P-2413  
BIBLIOGRAPHY OF SNAP REPORTS TO THE AEC from the Martin Company.  
August 1960. (AGN Lib. 1-456)
- 8.000 SNAP I Mercury Boiler Development, January 1957 to June 1959  
Jicha, John and Keenan, James J.  
Martin Co. Nuclear Div., Baltimore  
MND-P-2309. June 1960, 102p. Contract AT(30-3)-217

The mercury-boiler development program was undertaken to develop a system that would utilize the heat of radioisotope decay to boil and super-heat mercury vapor for use with a small turbine-generator package. Through the use of a Rankine cycle, the mercury vapor can be provided continuously to power a turbine-driven alternator and produce electricity for extended periods of time. This mercury boiler and the related power-conversion system was planned for a satellite that would orbit the earth. This system design and development program was designated as SNAP-I. Development of the mercury boiler is described and a chronological description of the various mercury-boiler concepts is presented. The applicable results of an extensive literature survey of mercury are included. The mercury-boiler experimental-test-program description provides complete coverage of each experimental boiler and its relation to the system design of that period. A summary of all mercury boilers and their final disposition is also given. NSA 15:13463

- 8.000 TID 7626 Pt-I NASA-AEC Liq. Metal Corr. Meeting (held) Dec. 14-15,  
1961 BNL, Upton Long Island, New York
- 8.000 AD 266 982L 1st International Congress on Metallic Corrosion  
Ralph R. Nash, 25 July 1961
- 8.000 AD267351 Proceedings of the Conference-Symposium on Materials  
Research in Canada held at U of B.C., Vancouver, B.C.  
6, 7, 8, June 1960.

Included in some work on liquid metals.

8.000 ALKALI METALS: LITHIUM, SODIUM, POTASSIUM, RUBIDIUM, AND CESIUM  
(Office of Technical Services, Washington, D.C.)  
July 1960, 37 p. (SB-4211) \$0.10 (OTS)

A bibliography of 672 reports listed in the two OTS monthly abstract journals: U. S. Government Research Reports and Technical Translations.

NSA 15:7691

8.000 LIQUID METALS  
(Office of Technical Services, Washington, D.C.) Aug. 1960  
10 p. (SB-424) \$0.10 (OTS)

A bibliography of 179 reports listed in the two OTS monthly abstract journals: U. S. Government Research Reports and Technical Translations.

NSA 15:7693

8.000 EMBRITTLMENT BY LIQUID METALS  
W. Rostoker, J. M. McCaughey, and H. Markus  
New York, Reinhold Publishing Corp. 1960, 169 p.

Published data on embrittlement by liquid metals are collected, reviewed, and evaluated. In addition, unpublished results of the latest research in this field are given. The seven chapters cover literature reviews, occurrence of liquid metal embrittlement, crack propagation, factors influencing embrittlement, delayed failure, theory of metal fracture, and mechanisms of liquid metal embrittlement, respectively.

NSA 15:1802

8.000 Liquid Metal Technology - A Literature Search  
Jacobs, James M., Comp.  
Technical Information Service Extension, AEC  
TID-3544, 1960, 27 p  
NSA 14:8679

Two hundred seventeen references to unclassified reports and published literature on liquid metal technology are presented.

8.000 THE ACCELERATED CORROSION OF METALS  
Third Quarterly Report, Initial Exploratory Studies,  
March 16 - June, 1960.  
David A. Jackson, Jr. (Virginia Institute for Scientific Research,  
Richmond). June 27, 1960. Contract DA 18-108-405-CML-518. 28 p.  
(AD-237775)

A survey to find a unifying principle that may be helpful in determining the mechanism of accelerated metal corrosion is reported. Corrosion found in a number of metals, when in contact with metals and alloys that are liquid below 35°C was observed. The types of deterioration noted include an accelerated oxidation rate of aluminum and magnesium in contact with Hg and its alloys and metal cracking such as that observed with aluminum, zinc, and tin in contact with gallium and its alloys.

NSA 15:13264

8.000 Liquid-Metals Corrosion Research (ANL)  
V. J. Rutkauskas, NASA TN-D-769, 1960.

Na corrosion on Experimental Breeder Reactor II program.  
NSA 15:13272

- 8.000 Liquid Metal Corrosion Research in SNAP (AI)  
M. A. Perlow, J. R. Crosby, NASA TN-D-769, 1960.

Introduction to SNAP-2, SNAP-8, and SNAP-10 systems. NaK corrosion of containment materials is summarized. NSA 15:13274

- 8.000 NASA-AEC Liquid-Metals Corrosion Meeting NASA TN D-769.  
Dec. 1960. Washington, D. C. AGN Lib. 1-946.

NSA 15:13269

- 8.000 Flow Patterns of Two-Phase Flow - A Survey of Literature  
Vohr, John H. (TID-11514) Contract AT(30-3)-187. 59p. Dec. 15, 1960.  
(CU-2-60-AEC-187-Ch.E)

A survey was made of the literature on flow patterns occurring in simultaneous gas-liquid flows through ducts. Descriptions of gas-liquid flow patterns and the terminology used in denoting them are presented. The experimental investigations from which the descriptions are taken are surveyed. The relations between flow pattern and pressure drop in gas-liquid flows are discussed. Horizontal, vertical, and vertical boiling flows were investigated. NSA 15:18192

- 8.000 ORNL-2685 Unc. Oak Ridge National Laboratory, Tennessee  
Papers presented at ANP Materials Meeting, November 16-18, 1954  
(Wright Air Development Center, Dayton, Ohio) March, 1959. 168 p.  
... corrosion of stainless steel and Inconel by Li, Na, and Rb  
.... corrosion characteristics of a number of metals and alloys in liquid lead...

NSA 14:24489

- 8.000 Final Report - A Review of Work from December 1953 to December 1958  
with Abstracts of Reports Issued. Posey, W. J., Editor  
MSAR 59-29, 20 March 1959, 73 p. Contract NObs-65426

This report completes the task order for research and development work on liquid metals, organics and water technology under Contract NObs-65426. A brief general review of the work accomplished during the 5-year life of the contract is followed by a list of all reports issued, along with an abstract of each.

NSA 13:12088

- 8.000 SB-401 Uncl.  
Office of Technical Services, Washington, D. C.  
Corrosion. Ten Year Bibliography. December 1959. 39p.

NSA 15:3040

- 8.000 THERMOCOUPLES FOR HIGH TEMPERATURE MEASUREMENT. A BIBLIOGRAPHY.  
A. C. Foskett. July 1959. 20p. BIS.  
AERE-Bib-125 United Kingdom Atomic Energy Authority. Research Group.  
Atomic Energy Research Establishment, Harwell, Berks, England.

A bibliography of 106 references covering the period 1954 to March 1959 is presented. The sources checked included Nuclear Science Abstracts, 1954 to 1959, Science Abstracts A and B, 1954 to 1958, Engineering Index, 1954 to 1957, Applied Science and Technology Index, 1957 to 1959, and indexes at AERE, Harwell. (J.E.D.) NSA 14-1-302

- 8.000 CF-59-10-124  
REACTOR COOLANT DECONTAMINATION: A LITERATURE SURVEY  
J. C. Mailen. Oct. 30, 1959, 34 p. OTS (ORNL)

Literature on reactor coolant and coolant loop contamination and decontamination was reviewed. Includes liquid metal.

NSA 14:18700

8.000 Literature Survey on Properties of Sodium Vapor  
Ervin, Guy, Jr.  
Atomics International, Div. of North American  
Aviation, Inc. Canoga Park, Calif.  
NAA-SR-Memo 4417 September 25, 1959, 13 p.

A literature survey was conducted to assess the adequacy of published data on the properties of sodium vapor and to obtain information to be used as a basis for recommending experimental work on further measurement of these properties. NSA 14:18892

8.000 EMBRITTLMENT OF SOLID METALS IN A LIQUID METAL  
W. A. Morgan  
(Dept. of Mines and Technical Surveys, Ottawa) Metal Treatment  
and Drop Forging 26, 333-9 (1959) Sept.

A review is given of the published work on the embrittlement of solid metals by lower melting-point liquid metals. Included in the discussion are some of the theories for intergranular failure resulting from soldering and brazing operations on stressed materials. (57 references)

NSA 14:18202

8.000 CA57:14850i  
"The Possible Mechanism for the Destruction of Stressed Metals Under the Influence of Liquid Metals," G. V. Karpenks, Tr. Seminara po Zharostockim Materialam, Akad. Nuck. Ukr. SSR Inst. Metallokeram. i Spets. Splavov, 1959 No. 4 79-85 (Pub. 1959).

A detailed literature survey is given. The most likely mechanisms seems to be the corrosive effect of liquid metals and the diffusion of liquid metals into the stressed metal lattice.

8.000 NAA-SR-4013  
SODIUM GRAPHITE REACTOR MATERIALS SURVEY  
B. R. Hayward (AI) September 15, 1959. 47p. Contract  
AT-11-1-GEN-8. \$1.25 (OTS)

This discussion reviews the general reactor concept and the specific materials used for the major reactor components.

NSA 13:21775

8.000 TWO-PHASE FLOW IN GAS-LIQUID SYSTEMS--A LITERATURE SURVEY,  
J. A. R. Bennett (AERE, Harwell, Berks, Engl.). Atomic Energy  
Research Estab. (Gt. Brit.) CE/R 2497, 58 pp (1958--  
113 references.

CA52-12465g

8.000 HEAT TRANSFER--A BIBLIOGRAPHY OF UNCLASSIFIED REPORT LITERATURE.  
James M. Jacobs and Gifford A. Young (Tech. Information Service  
Extension, Oak Ridge, Tenn.). U.S. Atomic Energy Comm. TID-3305,  
126 pp.(1957).--1031 AEC reports are listed.

This bibliography contains 1031 annotated references to unclassified reports on heat transfer held by the Technical Information Service Extension, Oak Ridge, as of July 18, 1956. Author, subject and report number availability indexes are included.

NSA 11:4849

CA51-7068g

8.000 Sodium and Bismuth Liquid Metal Fuel Systems; a Literature Search to June 30, 1957  
Vogel, Richard C. and Rodger, Walter, A.  
Argonne National Lab., Chemical Engin. Div. Lemont, Ill.  
ANL-5933 Nov. 1958 Contract W-31-109-3ng-38 54p.  
NSA 13:4235

8.000 TID 3305  
HEAT TRANSFER APPLICATION OF LIQUID LITHIUM, LIQUID METALS AND LIQUID METAL PUMPS. Frederick E. Frost and Glen Maynard. Oct. 26, 1956.  
15p. (M-6286)

This bibliography contains 126 references arranged under the following headings: Liquid Lithium, Liquid Metals, Liquid Metal Pumps, and General.

8.000 TID 3544  
Symposium on Corrosion Fundamentals. A series of lectures presented at the University of Tennessee Corrosion Conference at Knoxville on March 1, 2, 3, 1955. Anton de S. Brasunas and E. E. Stansburg, eds. Knoxville, University of Tennessee Press, 1956. 260p.

NSA 12:12908

8.000 AERE-Inf/Bib-93 (4th ed.)  
Gt. Brit. Atomic Energy Research Establishment, Harwell, Berks, England  
Electromagnetic Pumps and Flowmeters. A Bibliography of Literature References and Readily Available Reports by Greenhill, M. and C. S. Sabel, comps, October 1956. 1 Op. 55 references

NSA 11:6345

8.000 TID 3305  
REVIEW OF EXPERIMENTAL INVESTIGATIONS OF LIQUID-METAL HEAT TRANSFER.  
Bernard Lubarsky and Samuel J. Kaufmann. March 1955. 115p.  
(NACA-TN-3336).

Experimental data of various investigators of liquid-metal heat-transfer characteristics were re-evaluated using as consistent assumptions and methods as possible are then compared with each other and with theoretical results. The re-evaluated data for both local fully developed and average Nusselt numbers in the turbulent flow region were found still to have considerable spread, with the bulk of the data being lower than predicted by existing analysis. An equation based on empirical grounds which represents most of the fully developed heat-transfer data is  $Nu = 0.625 Pe^{0.4}$  where  $Nu$  represents the Nusselt number and  $Pe$  the Peclet number. The theoretical prediction of the heat transfer in the entrance region was found to give lower values, in most cases, than those found in the experimental work.

8.000 NP - 5714  
LIQUID METAL TECHNOLOGY. Final Report. (A review of the work from May 1949 to May 1954 with abstracts of reports issued).  
R. C. Werner. Mar. 29, 1955. 77 p. Contract N9onr-85801.

A final summary is presented of the various activities which have been carried out on liquid Na and NaK plumbing systems. Results on heat transfer, flow properties, corrosion tests, accessibility, Na cleaning, and tests on valves, bellows, pumps, etc. are included. Approximately half the report consists of abstracts of the various technical reports and memos which have been issued under the contract. (For preceding progress report see NP-5601.)

8.000 AERE-Inf/Bib-93 (3rd Ed.)  
Gt. Brit. Atomic Energy Research Establishment, Harwell, Berks, England.  
ELECTROMAGNETIC PUMPS AND FLOWMETERS.  
A Bibliography. M. Greenhill. 1955. 5p.

Available unclassified reports from the Geneva Conference, the A.E.R.E. and the A.E.C. are listed in this bibliography. (D.E.B.)

NSA 10:2699

- 8.000 KAPL-M-GHE-1  
Knolls Atomic Power Lab., Schenectady, N. Y.  
Report of Literature Survey on Liquid-Gas Entrainment Problems  
Epstein, Gilbert H. July 7, 1955. 16p. Contract W-31-109-Eng-52

An exploratory study has been made of literature pertaining to the phenomena of interfacial particles in gas-liquid systems to learn what factors influence the behavior of bubbles or other types of entrainment in both static and dynamic two-phase systems. The aim is ultimately to apply these findings and their corollaries to problems associated with filling and draining Na systems, where gas entrainment appears undesirable, both from heat transfer and hydraulic considerations. NSA 10:10817

- 8.000 A REPORT ON THE PROCEEDINGS OF THE LIQUID METAL UTILIZATION CONFERENCE  
(AERE) (1953) Report No. X/R 1381, 1954, p. 84.

- 8.000 A Report on the Proceedings of the Liquid Metal Utilization Conference Held in Abingdon, May 16, 1953. C. G. Banister, C. J. Heming, N. F. Goodway, and B. L. Tozer, eds. Mar. 26, 1954. 130p. (AERE-X/R-1381).

Papers on the following are included: design and operation of an apparatus for handling liquid Na and similar fluids; electromagnetic pumping of liquid metals, including reasons for adoption over mechanical forms, basic principles of operation, design of a small single-phase pump capable of handling Na of 200 to 500 kev, and a few notes regarding the large-scale pumping of liquid metals; use of liquid metals for high-temperature heat transfer, including properties, advantages as high-temperature media, design of heat exchangers, and application of liquid metals to nuclear power production and gas turbines; heat-transfer experiments with liquid Na; design and construction of a Na-steam superheater test plant; a study of Na-heated steam generating plant; and the application of liquid metals to reheating in a steam turbine plant.

- 8.000 LIQUID METAL COOLANTS. BIBLIOGRAPHY. J. E. Terry and N. B. Skeats. July 1954. 21p. (AERE-Inf/Bib 94).

A bibliography of unclassified reports and literature references supplementing, A.E.R.E. Inf/Bib. 89 and A.E.R.E. Inf/Bib. 89 (Supplement 1) and containing references up to mid-June, 1954 on liquid metal coolants is presented.

- 8.000 ORNL-1688  
Oak Ridge National Lab.  
SODIUM PLUMBING, A REVIEW OF THE UNCLASSIFIED RESEARCH AND TECHNOLOGY INVOLVING SODIUM AT THE OAK RIDGE NATIONAL LABORATORY. William B. Cottrell and Leland A. Mann. Aug. 14, 1953. 82p. Contract W-7405-eng-26.

The research data and the development experience relevant to sodium obtained during the period 1950 to 1953 at the Oak Ridge National Lab. are summarized. Methods for testing the corrosion resistance of structural metals in sodium and the results of such tests are presented. The developmental work that has been done on the various components of sodium systems is described, and the relative merits of commercially available components are discussed. Cleaning, assembly, leak testing, and operating techniques and precautions are given. (auth)

NSA 8:2824

- 8.000 LAMS-2779  
BIBLIOGRAPHY ON CORROSION BY LIQUID METALS. (1957- SEPTEMBER 1962)  
Helen J. Chick, Los Alamos Scientific Laboratory of the University of California, Los Alamos, New Mexico.

References on corrosion of or by alloys of the following metals: cerium, cobalt, iron, plutonium, tantalum, and tungsten. (This report contains 154 references.)



9.000

INDEXES



9.100

NUMERICAL INDEX FOR NUCLEAR SCIENCE ABSTRACTS (NSA)



<u>NSA Number</u>	<u>Page</u>	<u>NSA Number</u>	<u>Page</u>
5:3424	5-45	11:2264	3-89
			3-103
6:2362	1-17	2422	4-30
2909	1-16		4-35
6603	1-5	2437	6-11
	7-16		6-28
		2447	3-106
7:135	6-29	2448	4-28
183	2-41		4-36
			6-64
8:2824	2-42	2449	6-27
	4-15	2452	2-51
	8-10		4-24
		2464	6-25
10:2699	6-6	2475	6-27
	6-26		6-63
	8-9	2892	6-35
2717	2-4	2902	3-53
3198	5-46	3398	5-50
	3-86	3414	3-74
3493	3-94	3554	4-25
4687	5-44		6-37
6631	5-8	3789	2-108
	6-15	3791	1-41
6657	1-46		2-70
7622	5-4		2-101
7696	1-35		4-34
	2-15		4-1
8373	2-100	3885	5-45
8855	7-8		6-65
8876	4-20	3942	3-65
9303	3-78	4460	4-19
9305	3-78	4464	1-14
9306	3-78	4695	3-6
9307	3-77	4849	8-8
9308	3-77	4920	2-49
9776	5-5		6-38
10194	6-64	5305	6-25
10708	5-4	5311	2-45
10768	3-78		7-10
	3-89	5313	2-20
10817	5-51	5362	3-54
	8-10	5758	3-7
10821	4-36	6345	6-5
10822	4-29		6-26
10823	4-24		8-9
10825	6-6	6636	3-81
10832	2-95	6709	3-52
10835	4-28		6-47
10846	2-4	7189	4-18
10848	4-24		4-24
10865	3-20	7196	4-19
10954	5-51	7208	1-10
10958	6-28	7506	3-83
	6-65	7608	2-22
11171	3-115	8290	3-86
	6-26		3-104
11204	4-18	9285	1-33
11852	3-29		1-40
			2-51
11:1061	6-27	9330	2-59
1129	2-60	9570	6-8
1150	3-95	9725	1-27
2251	2-64		2-39
	2-76	9747	2-42

NSA ABSTRACTS (Cont.)

<u>NSA Number</u>	<u>Page</u>	<u>NSA Number</u>	<u>Page</u>
11:9747	7-4	12:8421	1-27
	7-7		2-71
11060	3-80	9135	6-23
	3-112	9147	2-35
11569	5-5	9444	2-59
11931	3-93	10093	1-13
12467	2-101		3-5
12564	4-17	10388	3-101
	5-8		3-103
	5-13	10593	6-51
12656	5-43	10637	3-29
13156	5-5	11414	6-35
	3-79	11846	6-64
13710	2-96	12435	3-31
	4-35	12467	3-50
	6-18	12513	6-10
		12515	6-11
		12908	8-9
		13081	5-30
12:212	6-35	13112	2-96
213	3-109	13148	1-37
	6-24	13149	5-6
287	3-50	13443	4-17
304	1-14	13908	6-30
522	3-95	14437	1-45
844	3-62	15105	2-91
846	2-50		4-12
1410	3-28	15501	2-35
1421	1-22	15603	1-31
1437	7-16	16355	2-92
1438	3-51		2-55
1611	3-50	16401	3-30
1926	4-37	16694	2-34
	6-62		4-12
2214	3-72	17222	2-18
2736	3-111	17306	5-38
	4-16	17329	3-21
2908	1-4	17793	5-34
3639	4-29		
	4-36	13:776	3-16
3652	6-24	1278	6-5
3653	6-24	1459	3-53
	6-61	1647	6-50
4462	3-65	1815	6-61
4842	4-18	2993	6-34
5199	5-42	3821	2-34
5396	2-62	3965	2-58
5654	2-83	4468	3-102
	5-29	5308	5-9
5952	3-52	6764	1-26
	5-11		2-36
	5-28	6787	2-58
5996	1-23		2-74
6195	5-28		3-90
6596	1-18	6832	2-35
6597	1-44	7817	3-4
6993	3-87	9065	1-10
7491	2-13		3-72
7791	6-50	9253	3-56
7806	2-40		6-53
7807	2-99	9255	3-51
7808	2-37	9358	5-43
7809	2-59	9372	3-75
8327	3-96	9684	3-32
	3-101	9759	3-110

NSA ABSTRACTS (Cont.)

<u>NSA Number</u>	<u>Page</u>	<u>NSA Number</u>	<u>Page</u>
13:9759	3-113	13:17212	3-48
10006	1-11	17327	6-33
10377	4-35	17336	2-90
	6-18	17781	3-101
11222	3-69	17874	3-92
11229	1-21	17902	3-110
11365	3-55	18104	2-57
11380	3-64	18855	3-92
11500	6-3	18904	3-107
11610	2-63		4-6
11611	3-88	19354	3-27
11653	6-14	19817	3-83
11820	3-5	20182	4-32
11838	2-63	20183	2-28
11851	4-7		2-41
	5-12	20199	5-42
12088	2-77	20208	3-12
	8-7	20275	2-34
12249	5-30	20496	3-57
12250	1-26	20497	5-25
12251	6-47	20888	3-83
12439	5-44	21084	3-94
12444	3-29		6-7
12488	3-98	21425	5-33
12647	2-91	21426	5-32
12652	2-19	21428	6-46
	2-24	21431	6-61
12676	4-23	21775	6-60
12678	4-22		8-8
	6-32	21776	6-60
12679	2-51	22387	4-18
12925	2-96		4-25
	3-58	22408	1-9
	5-35	22448	3-48
13087	2-45	23110	4-21
13225	3-69		
	5-41	14:171	3-100
13227	3-75	287	2-13
	6-49	297	5-27
13541	1-25	302	6-9
14057	5-27		8-7
14247	5-4	379	6-21
	6-14	574	3-27
14508	4-37	587	1-13
	6-65		1-38
14563	1-18	1106	2-92
14569	3-69		6-61
15594	3-48	1210	1-4
	5-24	1254	3-101
15599	5-25		6-14
15949	3-21	1608	6-45
16195	1-38	1609	3-63
	2-10	1610	5-26
16250	3-92	1684	3-23
16564	4-28	1762	2-52
16598	2-36	1763	1-13
	6-62		1-38
16599	6-50		2-72
16600	2-93		2-92
	4-13		2-99
	5-8	1804	4-20
	6-62		7-8
16738	3-92	2218	5-26
16752	6-60		7-19
16936	6-7	2538	6-45

NSA ABSTRACTS (Cont.)

<u>NSA Number</u>	<u>Page</u>	<u>NSA Number</u>	<u>Page</u>
13:2671	2-52	14:11708	6-21
	2-53	11724	5-25
	4-20	11922	2-75
		12292	3-5
14:2672	2-42		6-25
2690	2-53	12527	5-7
	7-11	12530	3-96
2692	2-38	12654	7-15
2695	2-34	12703	6-7
	2-45	12840	2-15
	2-49	12845	3-110
	2-90	12859	1-6
	2-106		2-13
	4-11	13830	2-69
2750	3-67		7-3
3175	2-89	14960	5-9
3499	1-10	15078	3-26
3846	3-47	15083	1-11
4123	5-25	15456	5-49
4128	2-77	15464	6-60
4291	6-10	15483	2-79
4318	3-95	15725	6-21
4421	3-49	15726	6-16
	6-46	15742	5-20
4422	5-26	15930	1-41
4434	6-7	16457	2-78
4437	6-27	16758	5-21
4500	2-73	16968	1-3
4784	3-64	17642	5-26
4950	2-49	17931	3-68
5064	1-8		3-107
	3-74	17950	6-31
	3-108	18202	8-8
5071	3-87	18643	7-13
	6-60	18644	7-13
5607	3-12	18645	2-79
6035	2-55	18646	5-35
6042	6-18	18700	8-7
	6-47	18853	5-43
6224	3-103	18892	3-18
6225	3-96		3-48
6416	3-26		8-8
	5-24	19055	5-8
6417	5-24		6-61
6755	3-87	19057	6-37
7485	6-20	19109	2-98
7493	6-34		5-23
7700	3-65	19111	5-20
8345	2-45	19310	2-56
	6-9	19311	2-34
8452	3-98		6-13
8761	3-12	20320	3-12
8767	1-36	20431	6-62
9480	3-103	20627	3-92
9737	2-88	21079	4-21
9810	4-18		6-37
10545	2-90	21108	3-47
10573	3-47	21160	5-20
10602	6-4	21879	2-56
11703	4-32	21881	2-56
	6-3	21882	6-2
	6-32	22038	3-8
11704	4-31	22067	1-24
	6-31	22069	3-69
11708	5-27	22615	5-20



NSA ABSTRACTS (Cont.)

<u>NSA Number</u>	<u>Page</u>	<u>NSA Number</u>	<u>Page</u>
14:22970	4-21	15:6202	2-57
	6-36		2-74
23226	7-5		7-20
	7-8	6405	2-57
	7-12	7691	8-6
23350	2-9	7693	8-6
	2-73	7701	1-26
23387	3-47		2-63
23757	2-65	7747	1-42
23838	2-79	7761	1-36
24215	6-43	8345	5-49
24216	2-99	8657	2-62
24230	6-43	8668	3-99
24488	2-78	8962	3-47
24508	2-89	9440	1-38
	2-103	10835	3-97
24510	2-61	10947	3-25
25542	3-103		6-3
25586	6-20	11052	5-41
26034	5-25	11612	3-106
26035	5-25	11639	1-10
26037	6-33	12475	5-48
26038	4-8		8-4
26039	6-45	12901	1-44
26040	6-45	12945	3-10
26041	2-18	13063	5-18
32691	2-92	13264	1-34
			8-6
15:163	3-91	13269	8-7
537	2-29	13270	1-44
	2-69	13272	2-33
	7-6		8-6
644	3-26	13273	3-11
1105	2-79	13274	2-65
1108	2-78		4-31
1109	2-78		8-6
1110	2-78	13275	2-85
1396	3-67		2-91
1490	5-21		5-23
1802	1-38	13276	2-85
	8-6		2-90
1886	3-26		7-9
2256	5-41	13277	2-17
2296	2-82		2-22
2297	2-89	13279	1-30
2565	3-67		1-31
2740	5-22		2-13
2746	5-22		7-7
2754	7-16		7-11
3044	8-7	13280	2-85
3773	5-22		2-90
3957	3-68		7-7
4080	4-22		7-11
4081	4-21	13281	2-85
4245	1-45		2-90
4250	2-44		7-9
4284	2-49	13283	4-8
4762	6-4		4-11
5157	3-46	13284	1-44
5552	2-93		2-85
5854	2-13		2-90
5856	2-79		2-98
6081	3-12	13285	7-8
6102	5-20	13286	2-82
6104	5-23		3-46

NSA ABSTRACTS (Cont.)

<u>NSA Number</u>	<u>Page</u>	<u>NSA Number</u>	<u>Page</u>
15:13357	3-11	15:24527	4-12
13414	3-27	24538	5-6
13463	5-26		5-27
	8-5	24805	3-94
13481	5-42	24945	4-20
13482	1-25	24953	2-44
13536	3-9		5-21
14029	2-96		5-22
14271	3-106	25218	3-45
14382	2-87	27721	4-21
14646	5-7	27748	5-18
14658	2-103	28558	1-12
14661	2-76	29117	3-99
14730	2-50	29123	3-99
15219	2-87	29545	5-40
15729	5-17	30331	5-20
15961	7-14		7-7
15962	7-14		7-10
16060	2-28	31137	1-44
	7-6	31910	2-82
16076	2-26		2-84
17352	2-7		2-98
17361	2-5	32565	3-24
	2-7	33035	5-49
17746	2-105		
17848	2-87	16:393	7-17
18166	4-7	619	3-10
18192	8-7	675	5-3
18436	2-52	1191	1-24
	5-48		2-88
18504	2-85		5-47
	7-5	1714	2-10
18505	2-28	1772	3-24
	2-84	1882	3-100
	7-15	2208	2-9
19378	3-45	2367	3-9
19392	3-66	2989	3-99
19492	4-27	3332	3-92
19523	2-78	4404	5-40
19904	3-10	4451	5-10
	5-48	4453	3-84
20477	2-82		3-87
	2-98	4534	3-9
	4-31	5084	5-4
	7-12	5088	3-3
20826	5-17	6692	2-50
21078	5-9		2-91
21096	1-21	7686	3-97
	1-44	9220	3-42
	2-17	11632	3-9
	2-24	11834	2-86
	3-26	12128	1-36
	7-10		2-10
21099	2-34	12147	3-25
21103	2-31	12649	2-25
22155	1-18	12660	2-61
22444	5-18		2-76
22640	5-27	12831	2-88
22692	2-17		3-44
22734	2-32		5-3
22739	3-46	13345	3-102
23641	5-22		5-47
23648	5-19	13537	4-4
23770	5-40		4-6
24501	5-6	13538	2-48

NSA ABSTRACTS (Cont.)

<u>NSA Number</u>	<u>Page</u>	<u>NSA Number</u>	<u>Page</u>
16:13538	2-68	17:282	3-25
	7-12		3-43
14354	5-13	398	2-13
	8-3	1979	3-8
14834	7-10	2461	2-82
	7-14		2-97
15146	2-99		5-13
15147	2-50	3421	1-7
	2-103	3425	2-43
15901	2-4	3484	3-19
	3-5		3-23
16687	3-91	3503	3-24
16692	2-48	5948	6-12
16741	3-39	6095	3-42
19377	3-11	6135	3-94
20320	3-97	6518	8-3
20975	8-4	6521	8-3
21039	3-8	6532	8-3
22047	7-17	6572	8-4
22155	1-33	6575	1-12
22160	2-36	6576	1-12
22310	3-42	6577	1-12
24145	2-54	6708	3-22
24165	2-31	7563	2-87
	2-54	7565	2-78
25402	1-38	7967	3-98
	2-73	8063	3-43
	2-97	8337	5-14
25522	3-43	8345	5-14
25714	2-67	8709	2-60
	2-73	9122	5-14
25720	2-50	9972	5-25
	2-106	10120	5-13
25782	3-23		
	3-109		
26475	5-10		
27160	5-40		
27570	1-24		
27584	2-9		
27586	7-7		
	7-16		
27594	2-97		
27629	3-19		
	3-24		
	3-42		
28538	1-43		
28545	2-77		
	3-11		
28554	3-6		
28560	3-99		
28561	2-89		
28647	2-104		
29128	5-39		
29340	2-76		
29406	3-8		
29604	3-8		
30167	2-12		
	3-82		
	3-91		
30564	3-39		
31303	2-81		
	2-87		
32087	2-12		
32956	5-47		

9.200

NUMERICAL INDEX FOR CHEMICAL ABSTRACTS (CA)



<u>CA Number</u>	<u>Page</u>	<u>CA Number</u>	<u>Page</u>
50:623i	2-70	51:11822	3-74
	5-32	11956	1-34
8260e	2-47		3-113
9811b	3-15	12625	3-52
15147	3-15	16010	3-85
15161	3-17		5-6
15164	3-93	16011	4-17
15179	3-31		5-11
15401	1-7	16011d	2-93
16074	3-79	16030	3-72
16199	3-85	16030e	3-32
	3-98	16199a	3-93
	6-15		6-62
16227	3-77	16260	1-3
16350	3-15		1-19
16645	6-9		1-22
17853i	3-57	17264	3-14
51:981h	1-9	52:230f	5-43
	2-108	1696f	2-105
	3-108	1736f	3-73
	5-3	1910i	3-74
	5-12	2485f	3-71
998a	1-40	3444a	1-11
	2-108		3-44
	4-8	3651h	3-87
	4-25	4437g	3-28
3169g	3-83	5189c	2-32
4065	3-53	7091e	1-45
4085	3-30		5-11
4118	3-51	8000	3-28
4158	2-40	8640	3-50
	2-84	8662a	3-17
	2-101	8910	2-37
5490	3-20	10655g	6-31
5498	3-19	12465g	8-8
5536	3-79	12478	3-18
5668	3-31	14247	6-37
6235	6-30	14268	3-27
6255	3-34	14478	3-112
6255a	3-16	18147	6-49
7065	2-10		6-51
	2-95	22945e	1-13
	4-32		
7065h	2-95	53:889h	3-5
	2-100	2702a	1-28
	3-53	2991f	1-4
	8-8		2-36
7068g	3-15	3004e	2-21
7080	3-111	3011e	2-21
7108	3-73		2-55
8400	3-18		2-92
8497	3-65	5833f	3-70
8603	3-18	7746c	3-69
9248	3-30	7855b	3-69
9447	4-7		3-102
10139	4-9	12116f	3-34
	4-17	16871h	3-27
	4-35	16898e	3-16
	5-27	17853e	3-16
	6-18	17853g	3-17
10195	3-111	21369d	3-100
10254d	3-64		
10965	6-51	54:5335c	3-100
117961	3-82	11674e	3-70

CA ABSTRACTS (Cont.)

<u>CA Number</u>	<u>Page</u>	<u>CA Number</u>	<u>Page</u>
54:14038f	2-55		
	4-27		
21945h	3-49		
55:6247d	3-110		
	3-113		
6250d	3-91		
16372f	2-53		
	4-19		
18519	3-90		
	5-9		
22945e	2-99		
	2-93		
23094e	2-43		
56:290e	3-44		
	6-41		
1310h	5-10		
	5-18		
2274g	2-12		
3090g	3-66		
	5-41		
3301i	6-42		
8032a	3-45		
8033h	3-24		
8260h	2-58		
9856h	2-11		
9908i	3-44		
	6-41		
11330b	5-40		
11390e	6-42		
11390h	3-45		
	5-19		
11391c	3-41		
12326	3-25		
12621i	1-29		
12689b	3-44		
13737c	2-57		
13767h	2-12		
14952e	3-49		
15169g	3-27		
57:8387g	6-15		
10895c	4-27		
10980c	5-39		
13580g	6-39		
14451	3-25		
14840	3-9		
14850i	2-107		
14906a	5-21		

9.300

LIST OF ABBREVIATIONS





ACR	Abstracts of Classified Reports
AD	Astia Documents
AECD	National Bureau of Standards, Washington, D. C.
AECU	Illinois Institute of Technology, Chicago, Illinois
AERE	Atomic Energy Research Establishment, Harwell, Berks, England
AGC	Aerojet-General Corporation, Azusa, California
AGN	Aerojet-General Nucleonics, San Ramon, California
AI	Atomics International, Canoga Park, Calif.
AiR	AiResearch Manufacturing
Ames	Ames Laboratory, Iowa State University, Ames, Iowa
ANL	Argonne National Laboratory, Lemont, Illinois
APDA	Atomic Power Development Associates, Inc., Detroit, Michigan
ARF	Armour Research Foundation, Chicago, Illinois
ASM	American Society for Metals
ASTM	American Society for Testing Materials, Philadelphia
BAPD	Westinghouse Electric Corporation, Bettis Atomic Power Division, Pittsburgh, Pennsylvania
BAW	Babcock and Wilcox Company, Research Center, Alliance, Ohio
BMI	Battelle Memorial Institute, Columbus, Ohio
BNL	Brookhaven National Laboratory, Upton, New York
CA	Chemical Abstracts
DEG	Development and Engineering Group, Culcheth, Lanes, England
GA	General Atomic Division, General Dynamics Corporation, San Diego, California
GEAP	General Electric Company, Atomic Power Lab., San Jose, California
GE-FPLD	General Electric Company, Flight Propulsion Lab. Department
GE-VAL	General Electric Company, Vallecitos Atomic Laboratory, Pleasanton, California
GE-HAPO	General Electric Company, Hanford Atomics Products Operation, Richland, Washington
KAPL	General Electric Company, Knolls Atomic Power Laboratory, Schenectady, New York
LA	Los Alamos Scientific Laboratory, New Mexico
MIT	Massachusetts Institute of Technology, Cambridge, Massachusetts
MSA	Mine Safety Appliances Company, Callery, Pennsylvania
NDA	Nuclear Development Corporation of America
NMI	Nuclear Metals, Inc., West Concord, Massachusetts

NPG	Nuclear Power Group
NRL	Naval Research Laboratory, Washington, D. C.
NSA	Nuclear Science Abstracts
NYO	Columbia University
NYU	New York University, New York, New York
ORNL	Oak Ridge National Laboratory, Oak Ridge, Tennessee
PWAC	Pratt and Whitney Aircraft, Connecticut Aircraft Nuclear Engine Lab., Middletown, Connecticut (CANEL)
SB	Office of Technical Services, Washington, D. C.
SRI	Southwest Research Institute
SRL	E. I. du Pont de Nemours and Company, Inc., Savannah River Laboratory, Aiken, S. C.
UCRL	University of California Radiation Laboratory, Berkeley, California
UTAH	University of Utah, Salt Lake City, Utah
WEST	Westinghouse Research Laboratories, Pittsburgh, Pennsylvania
TAPCO	Thompson-Ramo-Wooldridge, Inc.

9.400

MAJOR CONTRIBUTING ORGANIZATIONS

(CORPORATE AUTHORS)



MAJOR CONTRIBUTING ORGANIZATIONS

<u>Organization</u>	<u>Page</u>	<u>Organization</u>	<u>Page</u>
<u>AEROJET-GENERAL CORPORATION</u>		TID-3544	8-6
AGC-0390-SD-3	5-40		8-9
-0584-04-1	2-81	-5277	3-6
-0584-04-2	2-80	-5788	6-60
	4-3	-6045	5-21
-0584-04-3	4-3	-7525	4-14
-AE-34	5-11	-7526	1-14
-L2914-23	5-11		1-34
-SRP-R-397	2-31	-7529	3-29
	2-54		3-30
-SNAP 8	2-80		5-28
	2-102		5-29
	4-3		5-31
	4-30	-7568 (Pt. 2)	6-50
AGN-MCLP-11	2-81		5-4
		-7604	6-14
		-7621	4-7
		-7622	1-27
		-7623	5-10
AGN-EDS-159	2-16		1-12
	2-65		3-11
-AN-721	2-80		3-99
-AN-744	2-80	-7626	2-88
-AN-756	3-41		3-107
-AN-764	5-13		3-113
-AN-766	3-22		4-11
-AN-787	2-80		4-30
-AN-869	2-21		6-42
AGN-8016	7-14		6-59
-8034	7-10		7-5
	7-14		8-5
-8051	7-19	-8518	5-20
	3-105	-10048	5-28
TID-7626 (Pt. 1)	2-77	-11295	5-7
			5-48
<u>ATOMIC ENERGY COMMISSION</u>			8-4
		-11514	6-45
TID-1170	6-33		8-7
-1170-14	6-34	-11882	3-11
-3067	5-43	-12271	5-42
-3305	1-26	-12272	1-25
	3-54	-17384	1-12
	6-47	-17386	1-12
	8-8		
	8-9	AECD-3459	6-28
-3350	6-7	-3646	3-7
-3544	1-4	-3925	1-27
	1-18		
	1-31	AECU-1199	3-16
	3-16		3-62
	3-48	-1273	5-45
	3-72	-1495	7-8
	3-75		7-11
	3-97	-2627	5-36
	5-9	-2637	3-57
	5-41	-3200	5-45
	5-43		6-65
	6-7	-3285	3-78
	6-46	-3287	3-78
	6-49	-3288	3-78
	6-50	-3289	3-77
	6-60	-3290	3-77
	6-64	-3385	3-74
		-3519	3-73

MAJOR CONTRIBUTING ORGANIZATIONS (Cont.)

<u>Organization</u>	<u>Page</u>	<u>Organization</u>	<u>Page</u>
<u>ATOMIC ENERGY COMMISSION (Cont.)</u>		ANL-5115	3-81
		-5260	1-46
AECU-3519	3-110		2-40
-3656	5-49	-5345	6-64
-3658	6-61	-5359	3-81
-3700	6-48	-5640	1-24
-3747	5-3	-5719	5-43
-3777	4-17		6-49
-3853	6-5	-5914	3-5
		-5933	8-9
AEC-tr-2016	3-63	-6215	2-82
-2497	3-35		5-23
-2949	1-21	-6234	2-89
-2999	3-93	-6261	2-18
-3321	1-37	-6268	2-54
-3868	3-63	-6269	2-92
-4362	1-38		5-23
-4441	3-106	-6330	2-17
-4497	3-92	-6477	3-70
-4879	3-11		3-105
-5310	4-11	-6485	2-25
-5382	4-4		
	4-6	CF-3748	3-89
-5412	5-47		3-103
<u>AIRESEARCH MANUFACTURING (AIR)</u>		CT-3802	2-75
BNL-756	3-40	-3726	2-67
NASA TN-D-769	2-28	NASA TN-D-769	2-33
TID-7626	2-28	<u>ATOMICS INTERNATIONAL (AI)</u>	
	2-30	NAA-SR-74	1-27
	2-32	-126	2-41
<u>AMES LABORATORY (Ames)</u>		-258	2-39
IS-190	2-13	-469	6-33
-195	3-9	-528	1-27
-273	3-21	-557	2-49
TID 7526 (Pt. 1)	3-30	-758	2-60
		-878	3-17
		-1109	2-60
<u>ARGONNE NATIONAL LABORATORY (ANL)</u>			2-63
ANL-4003	2-75	-1115	2-58
-4029	3-62	-1171	2-63
-4069	2-75	-1178	6-3
-4092	6-54		6-32
-4150	2-75	-1292	2-46
-4188	2-75		2-62
-4238	4-34	-1300	2-3
	6-29	-1328	6-16
	3-62	-1509	3-98
-4278	1-16		3-103
-4417	2-30	-1552	5-43
	2-79	-1582	2-39
	2-97	-1662	6-30
	2-101		6-35
-4458	3-62	-1760	2-39
-4554	4-33	-1804	2-37
	6-11		4-14
-4596	3-104	-1867	2-59
	5-32		2-107
	6-28	-1875	2-94
	2-105	-1990	2-49
-5060	5-36	-2061	3-100
	6-55		3-110
-5090	2-75	-2169	2-59
		-2184	4-22

MAJOR CONTRIBUTING ORGANIZATIONS (Cont.)

<u>Organization</u>	<u>Page</u>	<u>Organization</u>	<u>Page</u>
ATOMICS INTERNATIONAL (Cont.)		NAA-SR-5661	2-87
NAA-SR-2184	6-34	-5687	3-67
-2414	4-25	-5732	3-97
-2576	2-49		6-12
-2616	6-32	-5777	6-20
-2830	3-88	-5951	4-27
	5-8	-6064	3-111
-2973	2-43	-6094	2-91
	2-45	-6162	2-44
-3216	2-14		5-47
-3407	6-4	-6303	6-17
-3481	2-57	-6306	1-17
-3638	3-87		1-20
	6-60		1-29
-3829	5-49		2-22
-3882	6-61		2-23
-3961	6-36		2-81
-4005	3-100		4-5
-4013	6-60	-6374	4-20
	8-8	-6386	5-10
-4050	2-93	-6408	5-4
	6-61	-6439	2-65
-4119	4-21		4-30
-4144	6-7	-6674	2-57
-4156	2-77	-6798	6-42
-4195	6-7	-6801	1-43
-4204	4-22	-6986	3-97
-4386	2-88		6-13
	5-49	-7325	5-19
-4387	6-31		5-48
-4388	6-20	-62	3-61
-4413	6-21	AI Memo-6416	7-7
-4417	3-18		7-16
	3-48	BNL-756	2-16
	8-8		3-40
-4436	6-31		3-41
-4537	6-15	NASA TN-D-769	2-65
-4545	3-96	TID-7623	3-6
-4578	3-87	-7626 (Pt. 1)	2-33
-4754	6-44		2-61
-4802	3-87		2-65
-4869	4-21		2-72
	6-36		2-88
-4873	5-20	-14979	2-61
-5004	6-21		2-79
-5106	6-21		
-5144	6-19	<u>BABCOCK AND WILCOX (BW)</u>	
-5241	4-21	BAW-1019	2-45
	6-36		2-93
-5244	4-31	-1170	2-45
-5261	2-57	-1252	2-13
	2-74		
	7-20	BW-3792	2-40
-5282	2-48	-3794	2-96
	2-89	-3988	2-99
	2-103	-5039	6-19
-5350	2-44	-5060	3-6
-5363	1-24	-5204	6-8
	2-88		6-28
	5-47	-5205	6-6
-5433	6-21	-7020	2-37
-5472	3-112		2-40
	6-15		2-94
-5615	6-59	-7050	2-59



MAJOR CONTRIBUTING ORGANIZATIONS (Cont.)

<u>Organization</u>	<u>Page</u>	<u>Organization</u>	<u>Page</u>
<u>BATTELLE MEMORIAL INSTITUTE (BMI)</u>		BNL-661	3-3
BMI-1152	2-56		8-4
-1189	2-56	-671	2-82
-1191	2-72		2-84
-1201	2-56		2-98
-1213	5-8	-728	1-35
-1220	2-56		1-38
-1284	2-93		2-32
-1344	2-13		2-54
-1400	2-72		8-4
-1405	2-55	-731	2-82
	4-27		2-97
-1442	2-34	-756	5-13
	6-13		2-16
-1477	2-13		2-77
-1538	3-99		3-8
			3-20
DMIC-42R	2-5		3-40
	2-6		3-41
-153	6-62		4-4
-166	1-25		4-5
-169	1-6		4-26
	1-17		5-51
	2-11		6-17
	2-29		6-36
	2-30		6-41
	2-65		6-57
	2-67		6-59
	2-73	-788	8-3
	8-4	-2433	3-55
		-2446	1-30
NP-10323	2-32		3-55
-11671	3-8		6-53
-11969	3-19	-2620	3-29
	3-24		5-31
	3-42	-4495	5-25
-12288	8-3	-5574	1-7
-12305	3-19	-5771	1-12
	3-23	-6102	1-7
-12417	8-3		1-42
TID-7626 (Pt. 1)	2-8		
	3-9	NASA TN-D-769	2-18
			2-33
NASA TN-D-769	2-13		2-77
		TID 7626 (Pt. 1)	2-21
<u>BROOKHAVEN NATIONAL LABORATORY (BNL)</u>			2-24
BNL-219	3-60		2-26
	6-55		2-29
-259	3-59		
	5-35	<u>COLUMBIA UNIVERSITY</u>	
	6-9	NYO-3086	1-17
-270	3-35	-3087	1-16
	5-34	-3088	1-16
-337	3-37	-3099	3-60
	5-31	-3100	3-59
-375	6-52	-3148	1-31
-489	2-58		3-60
-583	2-44		6-55
	5-26	-3150	1-32
-595	5-22		3-60
-659	5-20	-3152	1-32
	7-7		5-34
	7-10	-3154	1-32

MAJOR CONTRIBUTING ORGANIZATIONS (Cont.)

<u>Organization</u>	<u>Page</u>	<u>Organization</u>	<u>Page</u>
<u>COLUMBIA UNIVERSITY (Cont.)</u>		GEST-2012	8-3
NYO-3154	6-54	BNL-728	2-86
-4811	5-9	-756	3-40
-6217	3-58	TID-7626 (Pt. 1)	2-29
	6-5		2-30
-6320	3-80		2-86
-6330	3-53		2-88
-7638	3-53		
-7443	3-21	NASA TN-D-769	2-91
<u>JOHNS HOPKINS UNIVERSITY</u>		<u>KNOLLS ATOMIC POWER LABORATORY (KAPL)</u>	
ORO-60	3-38	KAPL-M-EEB-7	7-4
	5-38	-EEB-11	2-64
-70	3-38	-EGB-2	1-24
	5-38	-EGB-4	1-4
-76	3-37		2-52
	5-37		2-53
-89	3-37		2-71
	5-37		2-72
-93	3-37	-EGB-14	4-28
	5-37		4-64
-100	3-36	-EGB-16	3-113
	5-36		4-29
-121	3-36		4-35
	5-34	-EGB-19	2-101
-139	3-56	-EGB-21	5-51
		-EGB-22	2-69
<u>GENERAL ELECTRIC CO.</u>		-JB-11	5-36
GEAP-0500	2-4	-GJB-2	3-97
-3273	3-99		5-5
-3328	3-68	-GDC-6	6-34
	3-86		6-35
-3333	2-58	-PMC-1	4-24
-4006	7-17	-GHE-1	5-51
-4080	1-24		8-10
GE-63FPD66	1-36	-HAF-1	3-85
	4-9	-LFE-4	3-62
	7-6	-LFE-7	3-19
R-60 FPD-358A	3-46		3-20
GE-HAPO		-LFE-10	3-107
HW-40123	5-7	-LFE-16	2-40
-60564	3-48		2-84
-63052	7-15		2-101
-66562	5-41	-WLF-4	1-41
-74194	5-40	-WLF-5	2-23
-TR-27	7-17		2-70
GE-LMED			2-101
NP-8457	4-32		4-4
	6-3		4-34
	6-32		
-8458	4-31	-JMG-7	4-25
	6-31		6-37
-11824	2-31		
R49GL148	6-29	-JRG-2	3-78
R50GL231	4-37		3-89
	6-62	-WEJ-3	2-107
R51GL49	3-80		3-26
R54GL303	6-6		
R58-APS-116	4-32	-HFK-3	5-9
			5-13

MAJOR CONTRIBUTING ORGANIZATIONS (Cont.)

<u>Organization</u>	<u>Page</u>	<u>Organization</u>	<u>Page</u>
<u>KNOLLS ATOMIC POWER LABORATORY (KAPL)</u> <u>(Cont.)</u>		KAPL-197	4-20
		-200-19	8-4
		-267	5-46
		-294	5-45
		-337	2-47
KAPL-M-HFK-6	2-105		3-86
-JJK-1	4-24		5-46
-WWK-5	5-5	-362	5-38
-EDL-65	4-23	-532	5-34
	5-30	-557	2-64
-EDL-71	4-23		5-44
-EDL-100	5-5	-568	6-29
-EDL-107	4-13	-589	4-30
	4-23		4-35
-EDL-124	4-23	-612	3-88
	4-38	-619	6-28
		-635	6-36
-RWL-2	5-39	-877	4-35
-RWL-5	2-50	-1021	2-15
	2-109		3-106
	4-26	-1052	3-57
-FJM-1	2-107	-1079	4-28
	4-13		4-35
	5-30		6-64
-JJM-1	6-27	-1117	6-63
		-1177	6-27
-RLM-2	2-64	-1213	6-11
	2-76	-1367	5-33
	7-3		6-26
-NGM-1	2-51	-1653	3-111
-NGM-2	4-17	-1763	3-72
	5-8	-1797	2-37
	5-13		4-16
			5-30
-EJP-2	2-83	-1807	3-111
	2-108		4-16
	4-5	-2146	3-45
-WMP-1	3-51	AECU-2282	6-29
-FNS-6	6-28	AD-265571	2-3
	6-65	AD-256511	2-37
-JDS-1	6-56	TID-3305-930	2-96
-HLT-1	2-60		
	4-29	<u>LOS ALAMOS SCIENTIFIC LABORATORY</u>	
-LT-3	6-25	LA-703	3-95
-SCT-5	6-6	-2147	5-43
-SCT-8	5-5	-2327	2-55
-SCT-10	3-76	LADC-5403	3-43
-LBV-5	6-11	LAMS-2487	2-54
	6-28		6-9
-FWW-1	2-59	-2531	2-88
-HHW-2	2-109		2-102
-WW-2	2-75	-2541	5-19
	2-109		6-43
-JEZ-1	2-71	-2779	4-12
	2-106		6-43
	5-46	AECU-3519	8-10
	6-48	TID-10048	3-73
KAPL-P-1511	5-4		5-28
-116	6-49		

MAJOR CONTRIBUTING ORGANIZATIONS (Cont.)

<u>Organization</u>	<u>Page</u>	<u>Organization</u>	<u>Page</u>
<u>MARTIN CO.</u>		NP-5811	3-32
MND-P-2309	5-26		5-5
	6-45	-5814	4-33
	8-5	-5840	4-20
-2375	5-25		5-50
-2376	5-25	-5872	6-8
-2378	6-33	-5912	4-15
-2379	4-8	-5921	6-25
-2380	6-45		2-70
-2381	6-45		3-114
-2382	1-22		6-38
	1-29	-5935	6-47
	1-30	-5990	5-50
	4-5	-6051	5-45
			2-68
			2-100
		-6132	6-46
		-6178	5-50
		-6179	5-50
<u>MINE SAFETY APPLIANCES (MSA)</u>			6-46
NP-1108	6-6		4-19
-1392	5-38	-6202	6-49
-1423	3-80	-6209	2-49
-1527	3-104	-6220	6-38
	6-64		4-19
-2111	6-56	-6292	3-79
-3440	6-52	-6429	3-114
-3380	4-37	-6458	6-34
	6-19		4-23
-4010	3-38	-7389	4-22
	3-61	-7391	6-32
-4130	4-37		3-89
-4906	2-67	-7394	6-64
-5169	3-62	-7403	4-7
	6-56	-7410	5-12
-5279	6-53		3-88
-5350	6-53	-7415	5-44
-5449	7-19	-7418	
-5477	7-10		3-12
-5483	2-46	NP-tr-343	6-25
-5491	3-55	-355	5-6
-5601	1-46	-615	5-27
	2-60		5-27
	2-104	-645	
	3-12	MSAR 59-29	8-7
	3-33	MSAR 59-99	2-34
	6-16		2-45
-5601	2-63		2-49
	3-33		2-77
	6-65		2-90
-5689	6-38		4-11
-5690	2-95	MSAR 62-126	2-43
	3-32		
-5714	4-14	Tech. Report No. 47	3-115
	4-32		4-34
	5-32	Memo Report No. 49	6-27
	8-9		
-5727	3-55	Tech. Report No. 50	6-5
	6-52		6-63
-5739	2-95	Memo Report No. 107	6-37
-5751	2-104		
	5-32	Ad-256511	2-14
-5752	4-14		2-104
	5-33	NRL-C-3105	5-46
-5779	3-33	NASA TN-D-769	2-85
	5-33		2-90
		TID-3544	2-63

MAJOR CONTRIBUTING ORGANIZATIONS (Cont.)

<u>Organization</u>	<u>Page</u>	<u>Organization</u>	<u>Page</u>
<u>NASA LEWIS RESEARCH CENTER</u>		TID-3544	3-30
NASA TN-D-769	1-30	TID-7626 (Pt. 1)	3-31
	1-31		3-66
	1-44	NAVEXOS-P-733	3-6
	2-85		3-7
	2-90	AD-254791	3-70
	4-8	AD-278354	2-3
	4-11	NAM-RS-7045	2-45
	4-31		3-70
	5-23		
	6-13		
	6-60		
	7-7	<u>NORTH AMERICAN (ROCKETDYNE)</u>	
	7-8	NP-9236	2-93
	7-9	-10005	2-28
	7-11		7-6
	8-6	-10146	2-85
	8-7		7-5
NASA TN-D 1188	2-82	-10147	2-28
	5-13		2-84
	5-16		7-15
	6-41	NASA TN-D-769	2-85
	7-15		2-90
	8-3	NAA-R-3159	4-10
NASA Memo 2-5-59	3-48	-3159-2	4-10
	5-24		
NASA-5244	6-60		
-N 62-11319	3-91	<u>OAK RIDGE NATIONAL LABORATORY (ORNL)</u>	
-N 62-15816	6-20	CF-51-9-152	2-22
NACA TN-3336	3-54	-53-12-12	1-26
NASA-TT-F 88	3-25	-53-12-42	2-63
TID-7626 (Pt. 1)	2-24	-54-1-155	5-33
	2-27	-54-6-188 Del.	3-18
	2-33	-54-8-225	2-96
	2-81		6-18
AD-282370	3-42	-54-8-234	6-30
AD-270775	3-42	-54-9-98	2-53
		-54-12-26	4-18
			4-26
<u>NAVAL RESEARCH LABORATORY, (NRL)</u>		-55-6-24	2-95
NRL-4506	3-55	-55-7-16	5-4
-5344	3-40	-55-11-102	3-90
-5803	2-8		5-4
-5844	3-42	-55-12-120	5-32
	3-109	-56-1-151	3-83
-C-3105	5-46	-56-4-31	3-22
-C-3201	2-67		3-86
-P-2958	3-63	-56-4-73	3-104
-Memo-581	2-45	-56-5-148	2-38
	2-51	-56-7-135	4-34
-Memo-591	2-92	-57-2-146	6-45
-Trans. 659	3-31		1-13
AD-284340	3-40		1-26
	3-42	-57-3-35	2-93
NASA TN-D-769	2-33	-57-3-135	2-99
	2-54	-57-7-115	2-22
			2-38
PB-131065	1-22		1-21
NRL-Memo-47	3-18	-59-2-46	2-94
		-59-10-124	2-45
			8-7

MAJOR CONTRIBUTING ORGANIZATIONS (Cont.)

<u>Organization</u>	<u>Page</u>	<u>Organization</u>	<u>Page</u>
<u>OAK RIDGE NATIONAL LABORATORY (Cont.)</u>		ORNL-2349	2-52
			2-72
CF-59-11-67	3-47	-2391	2-32
-60-3-164	2-99		2-61
	5-24		2-62
-61-4-77	2-52	-2422	1-13
	5-48		2-53
			2-93
Y-811 (Supl.)	5-40		2-99
ORNL-ANP-60	2-79	-2431	2-83
			5-29
BNL-756	3-40	-2483	6-11
		-2544	6-34
NASA-TN-D-769	2-85	-2630	1-25
	2-90	-2669	5-25
ORNL-360	3-5	-2685	2-38
-415	3-63		8-7
-858	7-13	-2793	6-4
-910	7-13	-2871	2-18
-919	7-13		2-20
-987	7-13		3-68
-1033	2-52		3-107
	4-20	-2942	7-12
	7-13	-2988	7-6
-1108	2-42		2-29
	7-13		2-69
-1161	3-65	-2993	3-103
-1170	2-79	-3029	2-85
-1215	5-16		7-9
	7-19	-3074	2-27
-1330	6-45	-3114	7-5
-1375	2-79	-3144	7-14
-1439	2-79	-3160	2-30
-1515	2-79		7-12
-1609	5-35		7-19
-1647	2-42	-3168	6-24
	7-4		6-61
	7-7	-3226	2-27
-1688	2-42		7-5
	4-15		7-14
	8-10	-3270	2-84
-1716	3-57		7-14
-1729	7-5	-3313	1-33
	7-8		1-43
	7-12		2-12
-1771	2-78		2-27
-1896	2-78		3-82
-1934	2-53		3-84
	4-19		3-91
	4-20	-3337	2-84
	7-8		
-1947	2-78		
-2012	6-18	<u>PRATT AND WHITNEY AIRCRAFT</u>	
-2061	2-65		
-2080	2-78	PWAC-203	2-99
-2106	2-78	-292	6-16
-2147	6-64	-572	2-37
-2217	2-15	-583	2-55
-2271	2-38	-592	2-72
	2-43	-593	2-98
-2292	6-7		4-32
-2340	2-104	-604	2-12
-2348	2-34		3-11
	4-12	CNLM-2422	4-31

# MAJOR CONTRIBUTING ORGANIZATIONS (Cont.)

<u>Organization</u>	<u>Page</u>	<u>Organization</u>	<u>Page</u>
<u>PRATT &amp; WHITNEY AIRCRAFT (Cont.)</u>		<u>UNIVERSITY OF CALIFORNIA RADIATION LABORATORY (UCRL)</u>	
BNL-756	3-8 3-40	UCRL-1241	3-21
TID-3544	3-64	LWS-24338	3-65
-11894	2-50	-24734	3-65
-12224	2-48 2-50	-30103	3-64
-12232	2-91	N-62-157	3-4
-12245	2-50 2-103	TID-2502	3-21
-12268	2-50 2-103 2-76	<u>UNITED STATES AIR FORCE</u>	
TIM-65	3-9	AD 257 693	3-44
-490	2-48 2-50 2-91	AD 261 775	3-48
NASA TN-D-769	3-11	AD 266 768	3-50
<u>SOUTHWEST RESEARCH INSTITUTE</u>		AD 270 481	3-43
AD 230 065	3-3	AD 277 379	2-97
AD 230 085	3-10	AD 282 159	3-45
WADD-TR-61-96	3-3	AD 282 370	3-42
<u>THOMPSON RAMO WOOLDRIDGE INC. (TAPCO)</u>		AD 284 165	3-3
ER-1057	1-22	AFOSR TR-59-32	3-47
-4057	2-18	AFOSR TN-657	3-47
-4103	1-21 1-44 2-17 2-21 2-22 2-24 3-26 7-10 7-12	Trans. No. MCL-993	6-42
-4106	6-31	ASD-TR-61-594	3-43
-5214	3-23	WADC-TR-53-373	8-3
-5302	1-12 1-28 1-31 1-42 2-24 6-66 3-53	-57-344	2-9
TM-777	1-42	-57-648	4-18
-1621	1-42	WADD-57-294	2-97
-3388-67	6-66	-TR-59-764	3-12
NP-11354	6-40	-TR-61-47	6-59
MND-P-2128	2-83	-TR-61-96	3-3
MND-P-2322	2-83	-TRE-9-764	3-10 4-28
MND-P-2382	2-17 2-26	<u>UNITED KINGDOM (BRITISH)</u>	
NASA TN-D-769	2-17 2-18 2-22 2-23	AAEC/E-2	5-30
		AAEC/E-4	6-47
		AAEC/E-22	3-92
		AAEC/E-23	3-92
		AERE-A/CONF. 15/P/25	1-26
		-Bib.-125	6-9
		-CE/R-1998	1-8
			3-74
		-CE/R-2158	3-108
			3-76
			5-44
		-CE/R-2497	8-8
		-CE/R-2618	2-62
		-CE/R-2763	3-14
		-ED/D-10	3-6
		-ED/M-28	6-33
		-ED/M-31	6-34
		-ED/R-1844	6-25
		-ED/R-1856	3-115
			6-26

MAJOR CONTRIBUTING ORGANIZATIONS (Cont.)

<u>Organization</u>	<u>Page</u>	<u>Organization</u>	<u>Page</u>
<u>UNITED KINGDOM (BRITISH) Cont.</u>		IGR-TN/C-857	2-35
AERE-Inf/Bib-93 (3rd Ed.)	6-6		2-92
	6-26	-TN/C-1019	2-55
	8-9	-TN/R-561	6-49
- Inf/Bib-93 (4th Ed.)	6-5	-TN/W-454	2-100
	6-26		3-114
- Inf/Bib-94	8-10	-TN/W-597	2-74
-M/M-148	1-34		2-75
	1-40	-TN/W-862	3-90
	2-51		4-62
	2-92	RDB (C)/TN-31	2-28
	5-11		2-41
-Med/R-2350	5-42	RDB (C)/TN-33	3-80
-M/R-1729	3-32		3-112
-M/R-1898	3-21	RDB (C)/TN-80	3-112
-M/R-2113	1-19		3-115
-M/R-2296	1-21	RDB(R)/TN-1	3-39
-M/TN-21	1-11	RDB(W)/TN-92	4-35
-M/TN-35	1-46		6-27
-R-3037	6-14	RDB(W)/TN-160	6-18
-R/M-95	6-35	RDB(W)/TN-198	3-56
-R/M-144	6-24		6-53
-R/R-1891	4-29	RDB(W)-8050	5-35
	4-36	RDB(W)-8054	2-96
-R/R-2190	3-50		3-58
	5-11	SM 26/49	2-72
	5-28		2-97
-R/R-2274	3-109	N-62-15836	3-64
	6-24		
-R/R-2275	6-24	<u>WESTINGHOUSE RESEARCH LABORATORIES</u>	
-R/R-2485	6-10	AD-281740	2-3
-S/PR-2087	1-39	ARDC-TR-59-66	2-4
	1-41		2-6
-X/M-85	1-5		2-8
	7-16	ASD-TDR-62-541	3-3
-X/M-169	6-4	WAPD-3	2-25
-X/PR-1087	2-46	WIAP-M-30	6-27
-X/R-1381	8-10		
-X/R-1503	2-19		
	2-24		
-X/R-1806	1-6		
	1-16		
	1-35		
	2-15		
ARDC/P-34	3-103		
AWRE-O-62/62	6-12		
DEG-Memo-826	1-44		
	3-76		
	3-89		
DGN-Memo-1166	2-89		
IGO-AM/CA-110	3-101		
	3-103		
-AM/CA-173	3-94		
-174 (O/CA)	3-83		
	3-94		
-176 (O/CA)	3-83		
-196 (O/A)	3-95		
-197 (O/A)	3-95		
IGR-R/CA-255	6-8		
-TM/D-090	6-14		





(Note: Numbers listed refer to outline paragraphs, underlined numbers are the major locations.)

A

ACTIVATION AND RADIOACTIVITY 1.240, 2.230, 2.330, 3.130  
ANALYSIS, Liquid Metals 3.300, 6.160, 7.420  
    Corrosion Products 1.320, 3.300, 3.400, 6.170, 7.420  
    Containment Materials 3.400, 7.430, 7.440  
    Gas 3.242, 3.300, 5.200, 5.600  
AUSTENITIC STAINLESS STEELS (300 SERIES) 2.120, 2.213, 2.233, 2.243

B

BEARINGS IN LIQUID METALS 4.140, 4.340, 4.440, 6.220, 6.500  
BELLOWS FOR NaK, Hg 2.400, 4.130, 4.330, 4.430, 6.500  
BIMETALLIC TUBES 1.420, 2.100, 2.210, 2.240, 2.350, 4.300  
BOILER CORROSION 1.330, 2.200, 2.310, 7.230, 7.340  
BRAZING ALLOYS FOR LIQUID METALS SERVICE 1.400, 2.216, 2.246, 2.350, 4.320

C

CARBON ANALYSIS 3.140, 3.300, 5.300, 6.160  
CARBON TRANSFER 2.232, 2.233, 2.330, 2.350, 4.311, 4.411  
CARBURIZATION 1.430, 2.233, 2.235, 2.350, 3.200, 5.600  
CLEANING 3.212, 5.100, 5.110, 5.120, 5.500  
CORROSION, Solution 1.100, 1.120, 3.400, 4.112  
    Alloying or Compound Formation 1.130, 3.140, 3.400  
    Products 1.320, 1.400, 1.420, 3.400, 5.200, 5.300  
CREEP STRENGTH 2.100 thru 2.140, 2.400, 7.460  
CRUD FORMATION 1.320, 3.200, 3.410, 6.500  
CRUD TRAPPING 1.620, 3.232, 5.200 thru 5.240, 6.500

D

DECARBURIZATION 1.400, 1.520, 2.232, 2.330, 4.311  
DEGASSING OF LOOPS 3.200, 5.100, 5.200, 5.500  
DEPOSITS OF CORROSION PRODUCTS 1.320, 3.200, 4.111, 4.311, 4.411, 7.420  
DIFFUSION, Gases 1.220, 1.410, 3.140  
    Dissimilar Metals 1.220, 2.330, 3.110, 3.140

E

EMBRIITLEMENT, Hydrogen 1.430, 1.500, 2.330, 5.300, 5.600

Corrosion 1.400, 1.510, 4.111, 4.311, 5.300

EROSION 1.310, 2.230, 4.114, 4.214, 6.150

F

FATIGUE 1.520, 2.130, 4.130, 4.330, 4.430

FERRITIC STEELS (9Cr-1Mo Steel, 5Cr Steel, Croloys, etc) 2.110, 2.212, 2.242

FLOW RATE - EFFECT ON CORROSION OR EROSION 1.300, 1.310, 4.114, 4.314

G

GAS, Dissolved 3.140, 3.200, 3.400

Effect on Corrosion 1.400, 1.410, 2.300, 5.300, 5.600

GAS ENTRAINMENT 3.200, 3.232, 5.200, 5.600, 6.500

GETTERING 1.620, 3.232, 3.242, 5.200, 5.300

H

HANDLING. LIQUID METAL 5.100, 5.500

HASTELLOYS FOR NaK SERVICE 2.244

HEAT TRANSFER, BOILING, AND CONDENSING 3.120, 5.400, 6.400, 7.240

HYDRIDE ANALYSIS 3.232, 3.300, 7.420

HYDRIDE PRECIPITATION 3.140, 3.430

HYDROGEN ANALYSIS 3.200, 3.300

HYDROGEN SOLUBILITY IN LIQUID METALS 3.400, 5.600

I

IMPURITY, Analysis 3.231, 3.241, 3.300, 5.200

Effects 1.410, 3.200, 5.200, 5.300

INSTRUMENTATION 6.100 thru 6.170, 7.430

INSULATORS, Electrical for NaK 2.247

Thermal 2.247, 4.300, 6.500

L

LIQUID METALS - COMPATIBILITY OF MATERIALS 2.200 thru 2.247

LIQUID METALS - PHYSICAL PROPERTIES 3.110 thru 3.120

N

NON-METALLIC MATERIALS, NaK SERVICE 2.247

NON-WETTING 3.112

O

OXYGEN ANALYSIS 3.300, 6.160, 7.420

OXYGEN CONTAMINATION OF NaK 1.410, 1.620, 3.240, 6.170

P

PLUGGING OF LOOPS 1.320, 2.300, 3.400, 4.300, 6.170

PURIFICATION OF LOOPS 2.300, 5.100, 5.120, 5.200

PUMPS, EM (Electromagnetic) 6.210, 7.320

Mechanical 4.114, 6.220, 7.330

PURIFICATION, NaK 3.140, 3.242, 5.240

Hg 3.212, 5.210

R

RADIATION EFFECTS 1.240

REFRACTORY METALS, NaK AND Hg SERVICE 2.215, 2.245

S

SAFETY, LIQUID METAL HANDLING 5.500, 3.140

SEALS 4.121, 4.421, 6.220

STRESS CORROSION 1.230, 1.520, 2.400, 4.300

STEELS ((Cr-1Mo, 316 Stainless, 347 Stainless) 2.100, 2.212, 2.213

T

TEST TECHNIQUES 2.300, 7.100, 7.200, 7.300

THERMAL CYCLING 2.130, 2.400, 4.300, 5.400, 6.400, 7.200

THERMAL STRESS 1.230, 1.520, 2.400, 5.400, 6.400

TRAPS, Cold 1.620, 3.232, 5.200, 6.500

Crud 1.320, 3.212, 6.500

Filter 5.200, 6.500

Hot 1.620, 2.236, 3.232, 5.200, 5.230

Vapor 3.200, 6.500

TUBING, RADIATOR AND BOILER 2.120, 2.200, 2.240, 4.100, 4.300, 6.500

TURBINE MATERIALS 2.120, 2.223, 4.214, 6.500

V

VALVES 4.300, 6.300, 6.400

VAPOR EROSION 1.310, 1.340, 4.100, 4.114

VAPOR CORROSION 1.330, 1.340, 2.223, 4.100

VELOCITY EFFECTS 1.310, 2.200, 2.225, 2.230, 4.210

VISCOSITY, LIQUID METALS 1.130, 3.112

W

WELDS, LIQUID METAL SERVICE 2.100, 2.140, 2.230, 4.310

WETTING 3.112